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(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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JULY, 1955—VOL. 27, No. 7

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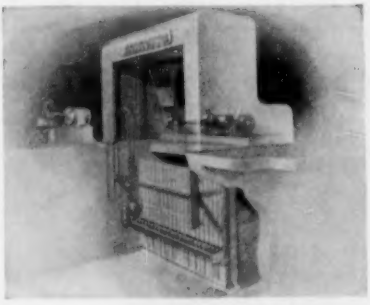

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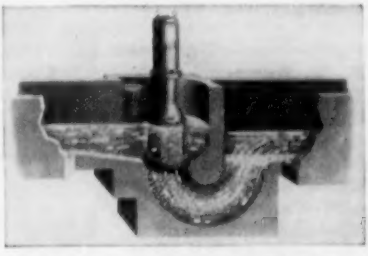

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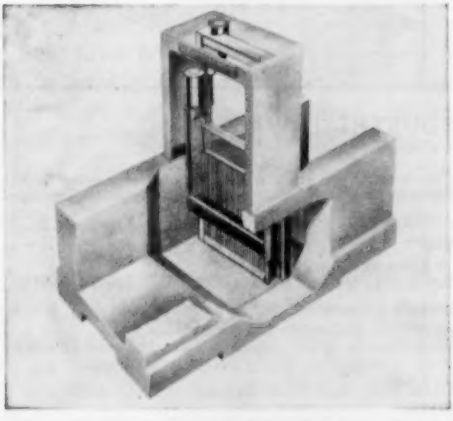

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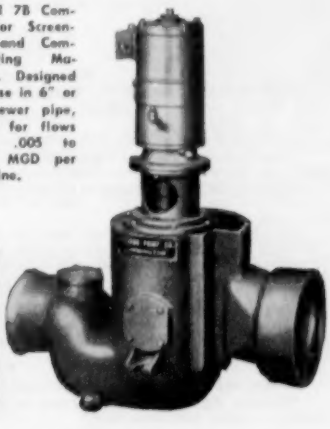

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Prince and Lemon Sts., Lancaster, Pa.

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4435 Wisconsin Ave., N.W., Washington 16, D. C. Send all manuscripts, advertising copy, subscriptions, address changes, etc., to this address.

SUBSCRIPTION RATES
Members of local sewage works associations affiliated with the Federation, $5.00 per year.

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Entered as second-class matter, May 7, 1934, at the post office at Lancaster, Pa., under the Act of March 3, 1879. Accepted for mailing at the special rate of postage provided for in the Act of February 28, 1925, embodied in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized October 4, 1945.

REFERENCE SERVICE
Sewage and Industrial Wastes is indexed regularly by *Industrial Arts Index* and *Engineering Index*.

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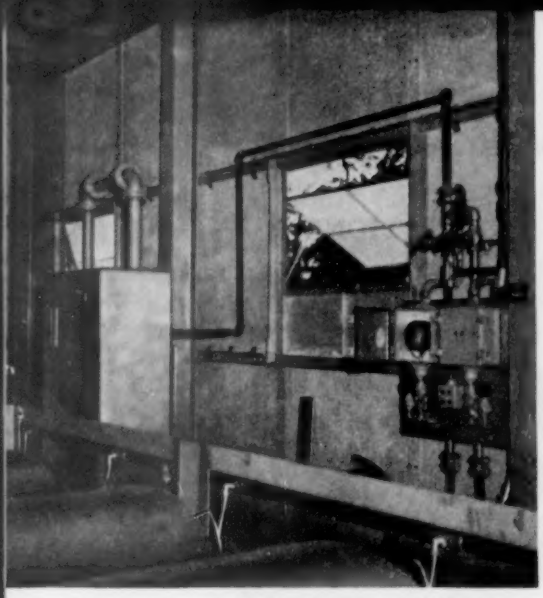
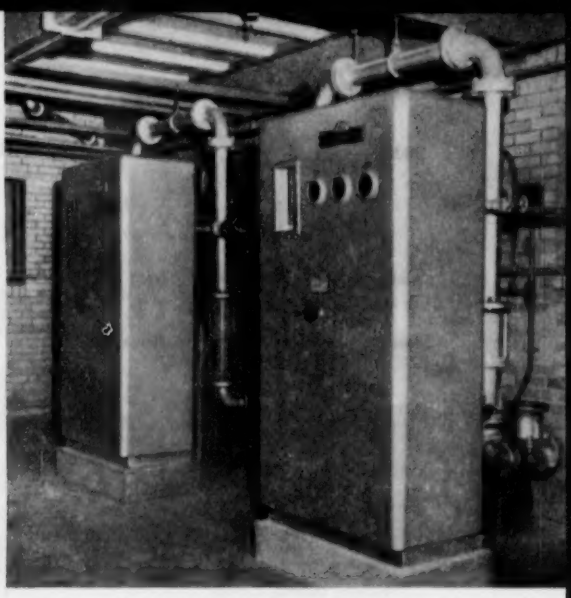


One of the two temporary chlorinating stations which served the Blackstone Valley Sewer District during the interim disinfection period. One of the Builders Chlorinizers can be seen in the background.



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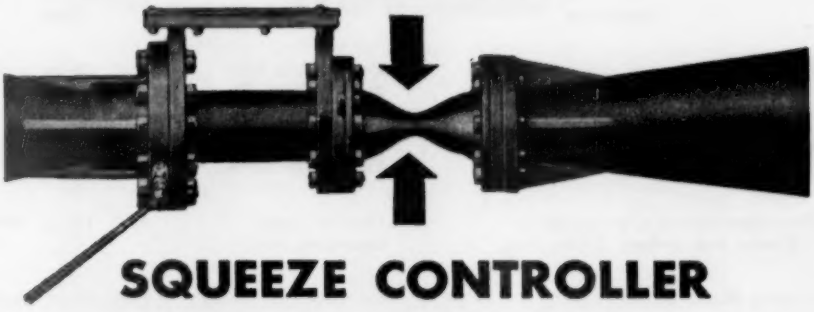

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Association	*Place*	*Time*
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Iowa Sewage Works Assn.	Hotel Waukonsa Fort Dodge, Iowa	Sept. 7–9, 1955
Kentucky–Tennessee Industrial Wastes and Sewage Works Assn.	Phoenix Hotel Lexington, Ky.	Sept. 12–14, 1955
Georgia Water and Sewage Assn.	Georgia Inst. Tech., Atlanta, Ga.	Sept. 21–23, 1955
South Dakota Water and Sewage Works Conf.	Brown Palace Hotel, Mobridge, S. Dak.	Sept. 21–23, 1955
Missouri Water and Sewerage Conf.	Connor Hotel, Joplin, Mo.	Sept. 25–27, 1955
Oklahoma Water, Sewage and Industrial Wastes Conf.	Oklahoma A. and M. College Stillwater, Okla.	Oct. 5–6, 1955

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in conjunction with

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Ambassador Hotel, Atlantic City, New Jersey

October 10–13, 1955

West Virginia Sewage and Industrial Wastes Assn.	Waldo Hotel, Clarksburg, W. Va.	Oct. 19–20, 1955
Florida Sewage and Industrial Wastes Assn.	Orange Court Hotel Orlando, Fla.	Nov. 6–9, 1955

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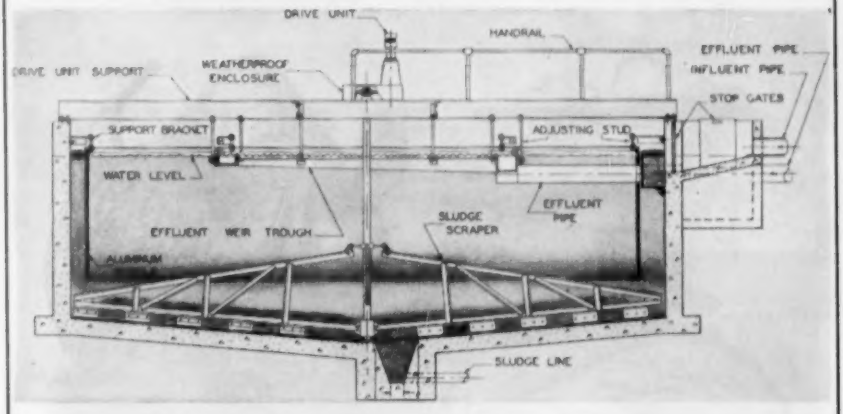

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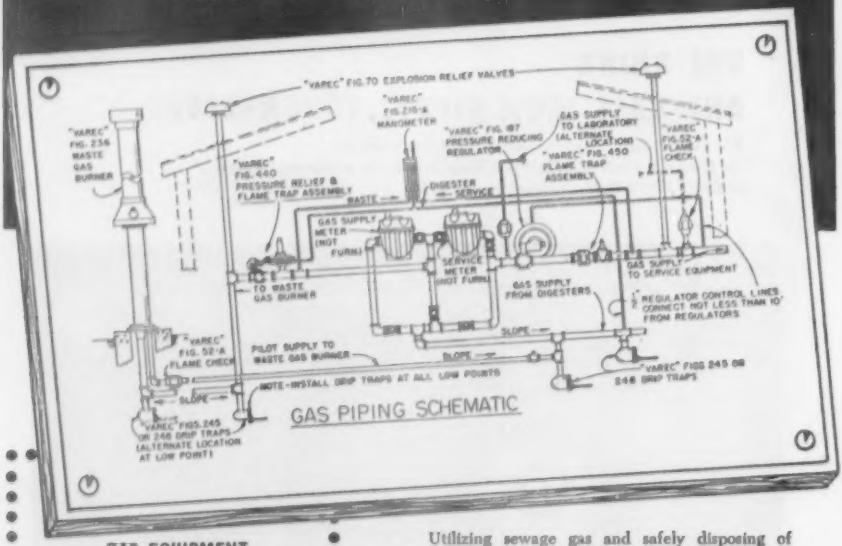
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 187 PRESSURE REDUCING REGULATOR
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"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
"VAREC" FIG. 52-A FLAME CHECK
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DIGESTER SERVICE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY TO SERVICE EQUIPMENT
TO WASTE GAS BURNER
GAS SUPPLY FROM DIGESTERS
REGULATOR CONTROL LINES CONNECT NOT LESS THAN 10' FROM REGULATORS
"VAREC" FIG. 52-A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
"VAREC" FIGS 245 OR 248 DRIP TRAPS
NOTE-INSTALL DRIP TRAPS AT ALL LOW POINTS
"VAREC" FIGS. 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
GAS PIPING SCHEMATIC

GAS EQUIPMENT SPECIFICATIONS

PRESSURE RELIEF AND FLAME TRAP ASSEMBLY
"VAREC" Fig. No. 440

FLAME TRAP ASSEMBLY
"VAREC" Fig. No. 450

FLAME CHECK
"VAREC" Fig. No. 52A

EXPLOSION RELIEF VALVES
"VAREC" Fig. No. 70-1

WASTE GAS BURNER
"VAREC" Fig. No. 236

DRIP TRAPS
"VAREC" Fig. No. 245 (automatic)
"VAREC" Fig. No. 248 (hand operated)

MANOMETERS
"VAREC" Fig. No. 216A

"Varec"

Utilizing sewage gas and safely disposing of excess gas is an automatic operation with "VAREC" Equipment incorporated into your sewage plant design. With this equipment, accurate gas pressures are maintained in all service lines. As soon as the digesters make more gas than required for service, the pressure relief valve to the waste gas burner opens to permit safe burning of the excess.

Flame flashback to valuable equipment is prevented with "VAREC" Flame Traps and Flame Checks. The flame arresting element of the Flame Trap is designed to eliminate flame propagation of even more inflammable gases than encountered in sewage service. This element is the same as that used in "VAREC" Flame Arresters listed by the UNDERWRITERS' LABORATORIES for petroleum product storage.

Emergency explosion relief is accomplished with "VAREC" Explosion Relief Valves. These valves should be installed outside of any buildings.

An enlarged engineering drawing of the above gas piping detail will be sent upon request. If you design sewage treatment plants, write today.

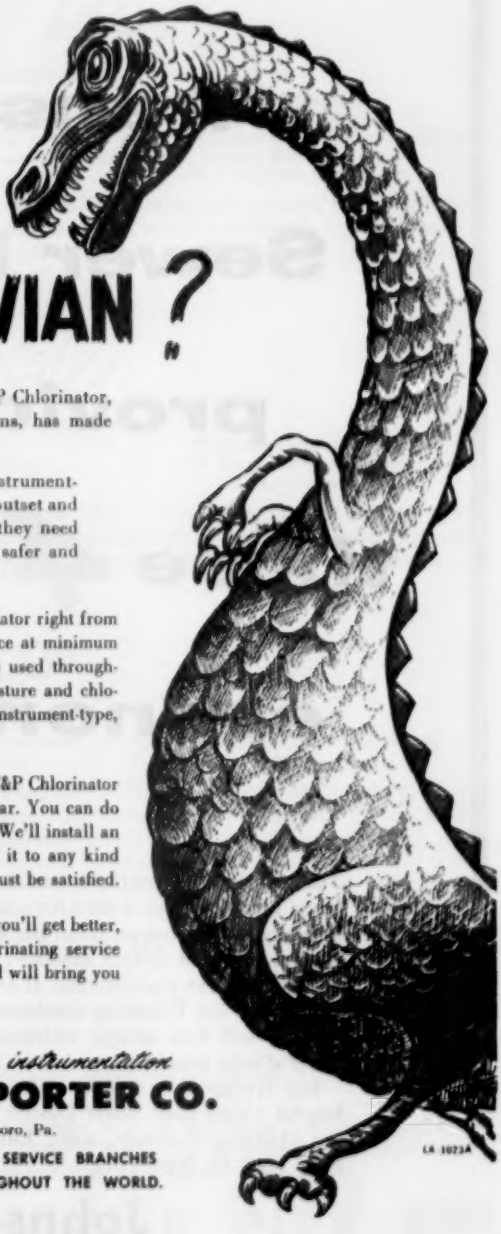
THE VAPOR RECOVERY SYSTEMS CO.
COMPTON, CALIFORNIA, U. S. A.
Cable Address: VAREC COMPTON USA (All Codes)

New York, N.Y. • Boston, Mass. • Pittsburgh, Pa. • Chicago, Ill. • Detroit, Mich. • St. Louis, Mo. • Houston, Texas • Tulsa, Okla. • San Francisco, Calif. • Seattle, Wash. • Minneapolis, Minn. • Honolulu, Hawaii

Available from authorized Sewage Equipment agents throughout United States and Canada

Are your chlorinators

ANTEDILUVIAN ?



The advent of the *fully mechanical* F&P Chlorinator, without any water trays or water columns, has made all others as dated as the dinosaur.

Now at last you can have modern, instrument-type chlorinators that cost less at the outset and save you money every day, because they need less servicing, less maintenance, are safer and easier to operate.

Fischer & Porter designed their new Chlorinator right from the floor up—to give maximum performance at minimum cost. New corrosion-resistant materials are used throughout. The fibre-glass cabinet is inert to moisture and chlorine. Regulators are modern, mechanical instrument-type, all completely corrosion-proof.

But don't take just our word for it. Let the F&P Chlorinator prove itself—in your own plant for one year. You can do this without risking a penny. We'll install an F&P unit next week. Subject it to any kind of test you can make. You must be satisfied.

You can't lose a thing—and you'll get better, safer, more economical chlorinating service from the first day. A postcard will bring you the facts. Mail it now.

complete process instrumentation

FP FISCHER & PORTER CO.

1175 Fischer Road, Hatboro, Pa.

COMPANY OWNED SALES AND SERVICE BRANCHES
STRATEGICALLY LOCATED THROUGHOUT THE WORLD.

Transite Sewer Pipe provides these 4 basic economies

The engineer, the contractor and the taxpayer—all benefit when Transite® Pipe is used for sewer lines. Costs are cut in many ways—among them the four basic Sewer Pipe economies . . . in system design . . . in installation . . . in operation . . . in maintenance. If you make a quick run-through of the following condensed check list, chances are you will find savings which apply directly to your sewer system problems.

For further information and your copy of TR-94A, helpful widely used Sewer Design Flow Chart based on the Manning Formula, write Johns-Manville, Box 60, New York 16, New York.

Johns-Manville

1. System Design

(Typical Economies)

- Use of smaller diameter pipe
- Installation at flatter slopes
- Installation in shallower trenches
- Savings in amount of material excavated
- Smaller earth loads
- Elimination of cradling
- Location of treatment plant at higher level
- Elimination of pumping

Users have found—With its high flow capacity (flow coefficient n=0.010 derived from the Manning formula) and with its maintained strength, Transite Sewer Pipe contributes to typical system design economies.

2. Installation

(Typical Economies)

- Fewer joints
- Easier Handling
- Smaller crews
- Speedier assembly
- Assurance that joints pass severe infiltration tests

Users have found—With its longer lengths, light weight, ease of assembly and tight, quickly made joints, Transite Sewer Pipe contributes to typical installation economies.

3. Operation

(Typical Economies)

- Infiltration treatment cost drastically reduced
- Only normal sewage treated

Users have found—With its tight joints connected by Johns-Manville's Ring-Tite® Coupling, Transite Sewer Pipe contributes to typical operation economies.

4. Maintenance

(Typical Economies)

- Tree roots kept out—minimizes cleaning
- Need for frequent inspections reduced
- Sewers kept smooth and intact—pipe stays strong, joints stay resilient

Users have found—With its maintained strength and with its tight joints, Transite Sewer Pipe contributes to typical maintenance economies year after year.

TRANSITE SEWER PIPE

the asbestos-cement sewer pipe with the tight joints

JOHNS-MANVILLE PRODUCTS

ASH or CA$H?

from your
SEWAGE DISPOSAL PLANT

The new sewage disposal plant in Wyomissing Valley, Pennsylvania (Albright and Friel, Philadelphia, consultants), could have been designed for incineration. But it wasn't. Here's why.

It was known that the sludge would be free from contaminants. By flash drying and selling this sludge, the plant could perform a service to the community and to itself. Dried sludge is rich in humus, is easy to handle and contains the elements found in good topsoil. After being dried, an excellent organic soil conditioner could be made available to the public at a reasonable price. At the same time, the expenses of incineration — ash handling and disposal, for example — would be avoided while the revenue from the sale of the dried sludge would help offset operating expense.

Naturally Wyomissing Valley chose cash not ash. And, since the plant is located within a few hundred feet of a new apartment development a C-E high temperature deodorization system is incorporated in the design to guarantee odor-free operation.

Actual operation of this plant has confirmed the wisdom of the decision made in Wyomissing.

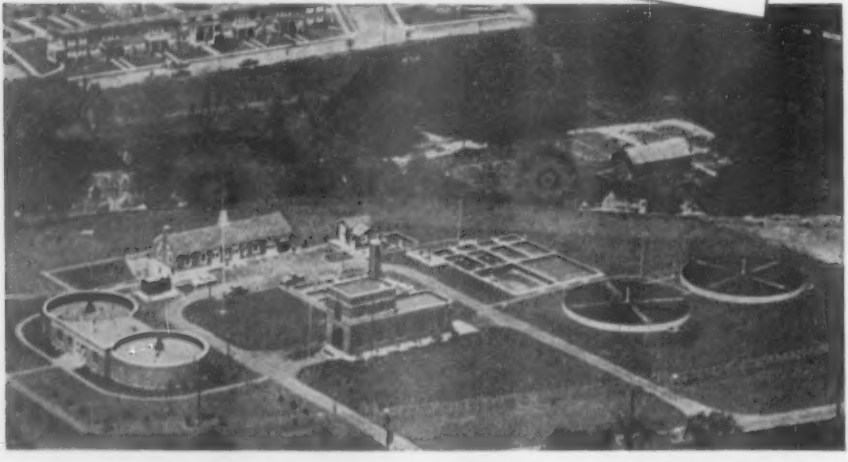
In communities where the character of the sludge makes it unsuitable for use as a soil conditioner, incineration may be the only answer. But, whether you plan to incinerate or dry, the C-E Raymond Flash Drying System can be designed to allow you to do either at will. Like the communities listed at the right, you too can end your sludge disposal problems effectively and at less cost with the service-proved C-E Raymond System. For full information, contact the C-E Raymond office nearest you. A C-E specialist will be glad to help you. B-810A

WYOMISSING VALLEY
PICKED CA$H

C-E

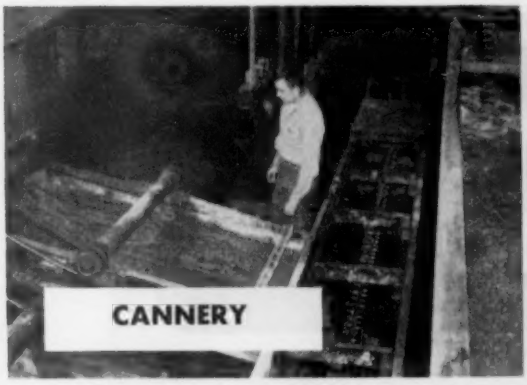
C-E RAYMOND FLASH DRYING SYSTEMS
PRODUCING FERTILIZER

CITY	TREATMENT	NO. UNITS	SIZE OF UNITS Lb. Water per Hour per Unit	INSTALLED CAPACITY Tons Fertilizer Per Year
Baltimore, Maryland	Act. Dig.	3	6,240	20,800
Battle Creek, Michigan	Prl. Dig.	1	2,370	2,500
Chicago, Illinois				
Calumet	Activated	3	6,667	15,850
Southwest	Activated	6	21,000	140,500
Southwest Ext.	Activated	6	21,000	49,500
Edgewater, New Jersey	Prl. Dig.	1	750	150
Fond Du Lac, Wisconsin	Prl. Dig.	1	2,350	1,300
Houston, Texas	Activated	2	12,000	20,400
Lansing, Michigan	Act. Dig. & Garbage	1	6,667	6,700
Los Angeles, California	Act. Dig.	4	22,500	79,500
Recife, Brazil	Prl. Dig.	1	943	1,300
San Diego, California				
#1 Plant	Prl. Dig.	1	3,500	7,500
#2 Plant	Prl. Dig.	1	5,000	13,200
San Francisco, California	Prl. Dig.	2	6,250	30,400
Schenectady, N. Y.	Prl. Dig.	1	2,370	2,570
Sheboygan, Wisconsin	Prl. Dig.	1	3,040	7,900
Stamford, Connecticut	Prl. Dig.	1	3,330	1,700
Washington, D. C.	Act. Dig.-Now	3	12,000	60,500
	Act. Dig. later	1	2,250	860
Wyomissing, Pennsylvania	Prl. Dig.			

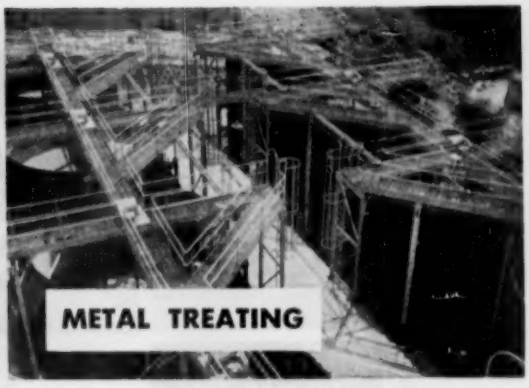


COMBUSTION ENGINEERING
RAYMOND DIVISION
1315 North Branch Street, Chicago 22, Illinois
Eastern Office: 200 Madison Ave., New York 16, N. Y. Western Office: 510 West Sixth St., Los Angeles 14, Calif.
ALSO FLASH DRYING AND INCINERATION SYSTEMS FOR INDUSTRIAL WASTE DISPOSAL

Whether waste presents PROBLEMS...



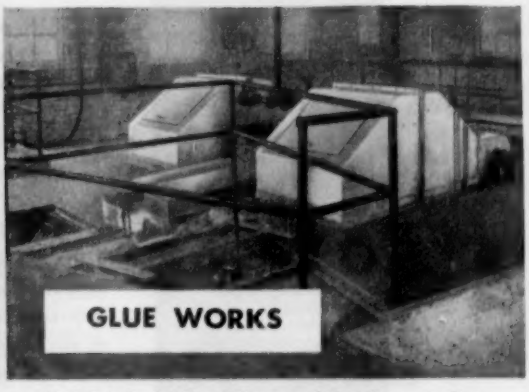
Link-Belt Thru-Clean Bar Screen, Straightline Grit Collector, flight conveyor and two liquid vibrating screens remove solids from waste water at midwest cannery.



Link-Belt flash mixers and thickener unit help separate toxic metals and cyanides from waste waters. Sludge thickening affords considerable savings in hauling costs.

or potential PROFITS...

Here profits were literally "going down the drain." But with Link-Belt Straightline Collectors installed, mill scale recovery rose from 250 to 475 tons per week.



Link-Belt Straightline Collector and Rotoline scum skimmer provide more efficient collection of solids, resulting in substantial reclaiming of grease and usable glue stock.

LINK-BELT knows how best to treat it

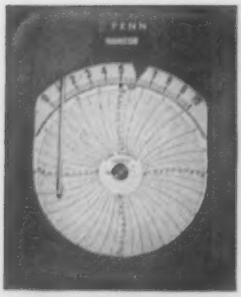
REGARDLESS of the nature of your waste . . . the size of your operations—Link-Belt experience and equipment assures a treatment system suited to your needs. If by-products are salvageable, Link-Belt can bring you maximum profits. Or if fast, low-cost waste treatment is the prime consideration, your answer lies in the job-proven efficiency of Link-Belt equipment. A call to your nearby Link-Belt office will put you in touch with a sanitary engineer. He's ready to work with your consultants and chemists—help you get the best in modern industrial liquids, water or sewage treatment equipment.

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

13.8H

LINK-BELT COMPANY: Executive Offices, 307 N. Michigan Ave., Chicago 1. To Serve Industry There Are Link-Belt Plants and Sales Offices in All Principal Cities. Export Office, New York 7; Canada, Scarboro (Toronto 13); Australia, Marrickville, N.S.W.; South Africa, Springs. Representatives Throughout the World.



OVER 45 YEARS OF FLOW METERING EXPERIENCE

THE PENN LINE IS COMPLETE FOR MATCHED METERING

DIFFERENTIAL PRODUCERS
Venturi Tubes
Flow Tubes
Open Flow Nozzles
Flumes and Weirs
Orifice Plates
Venturi Insert Nozzles
ASME Nozzles

METERS
Open Channel
Differential Pressure
Variable Area
Electric
Mechanical
Pneumatic
Totalizing
Indicating
Recording
Summation

CONTROLLERS
RECORDERS
Rate of Flow
Chemical Feed
Liquid Level
Loss of Head
Pressure
Temperature
Pump Operation
TELEPHONE LINE TRANSMISSION

The origin of Penn's present line of instrumentation goes back to 1909 when Cochrane meters were introduced. One of the earliest testing programs for open channel flow measurement was undertaken to develop these meters as reported at the 1914 A.S.M.E. meeting.

In 1918, an improved mechanical flow meter with no stuffing box was developed and in 1935 the first null-balance, servo-powered electric meter was produced. More than 10,000 of these meters have been installed throughout the world.

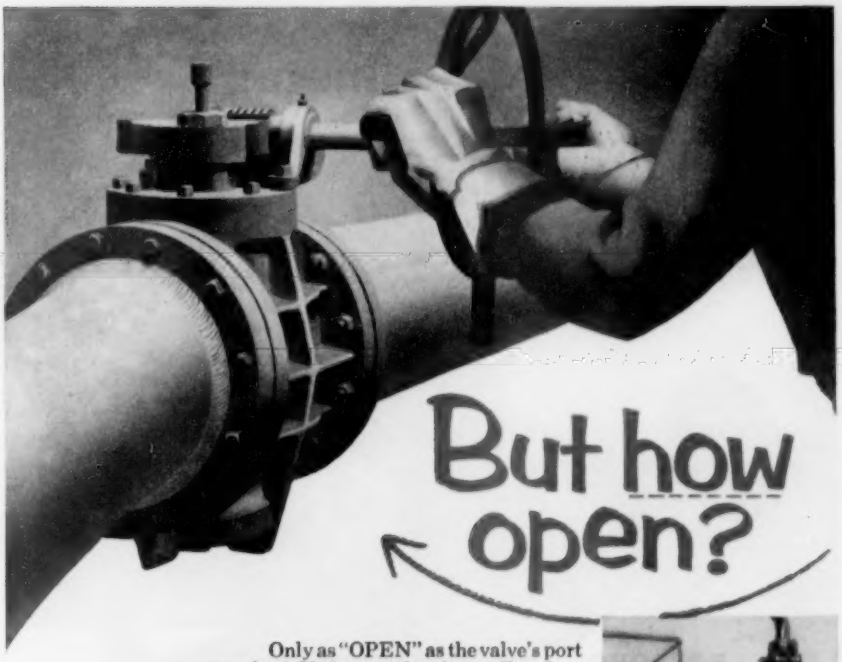
HIGHEST REPRODUCIBLE ACCURACY distinguishes Penn meters. Such accuracy is achieved only by a null-balance, servo-powered electric meter. To this unexcelled high fidelity of electrical transmission and recording, Penn adds the additional refinement of a calibration cam. This cam precisely matches the calibration of the recorder-totalizer with that of the differential producer. The result is "matched metering" and higher over-all accuracy.

MATCHED METERING

PENN *Instruments*

DIVISION OF BURGESS MANNING COMPANY

4100 Haverford Avenue • Philadelphia 4, Pennsylvania



But how open?

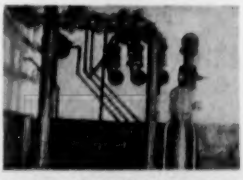
Only as "OPEN" as the valve's port opening! If the opening is smaller than the pipe... then a valve cannot be COMPLETELY "OPEN" in any position!

For a really "OPEN" flow...specify acf Rectanglar Port Valves. With a port opening the same area as the pipe itself ...they assure smooth-running, trouble-free operation by keeping down turbulence and harmful abrasive action caused by solids in suspension. They also minimize loss of head pressure... especially important when handling the extra heavy fluids used in the processing industries.

And, of course, all acf *Cylindrical* Lubricated Plug Valves...with rectangular or round port openings... feature "split-second" shut off, TEFLON* head gaskets, and many other design advantages. Representatives in 50 Principal Cities.

Write for descriptive Catalog 7-SI, acf Industries, Incorporated, Valve Division, 1501 E. Ferry Avenue, Detroit 11, Michigan.

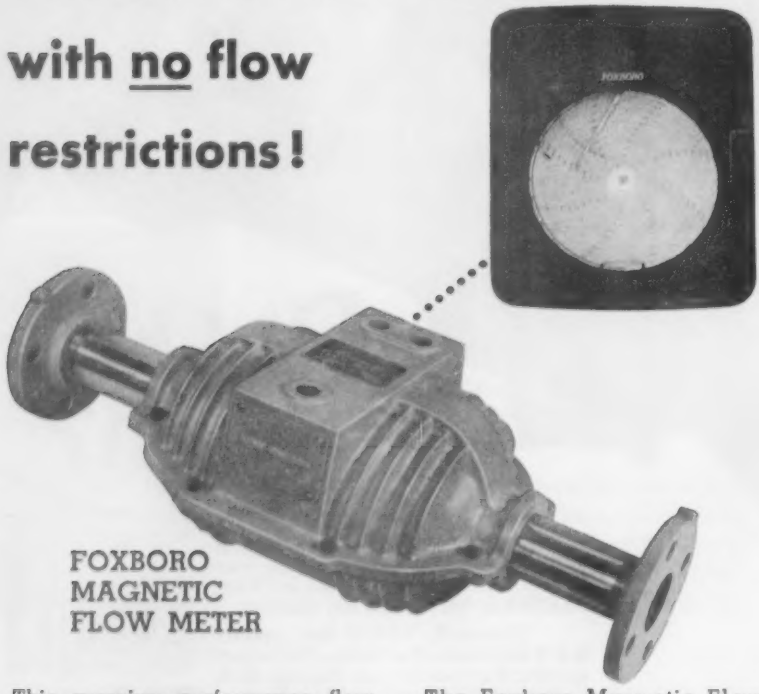
*DUPONT TRADENAME



acf Plug Valves are backed up by Proof-of-Performance in every Processing Industry.

acf CYLINDRICAL FULL PIPE AREA PLUG VALVES

NEW! a flow meter with no flow restrictions!



FOXBORO
MAGNETIC
FLOW METER

This premium-performance flow meter *magnetically* measures the flow rate of virtually any liquid except hydrocarbons — without adding any pressure drop to the line! It connects into the line like an equal length of pipe . . . has no pressure taps or moving parts . . . needs no maintenance. Overall accuracy is better than 1% of range *over entire scale* . . . even on rock-and-acid or sand-and-water slurries!

The Foxboro Magnetic Flow Meter operates on the same principle as a power generator. Liquid passing through its magnetic field generates voltage proportional to average velocity. This voltage is recorded directly in flow units by a Dynalog Recorder or Controller.

Available in standard sizes from 2" to 8" . . . larger if required. Write for full details on this more-accurate, trouble-free flow meter.

THE FOXBORO COMPANY, 887 NEPONSET ST., FOXBORO, MASS., U.S.A.

FOXBORO
Reg. U. S. Pat. Off.
Foremost in FLOW METERING

FACTORIES IN THE UNITED STATES, CANADA, AND ENGLAND

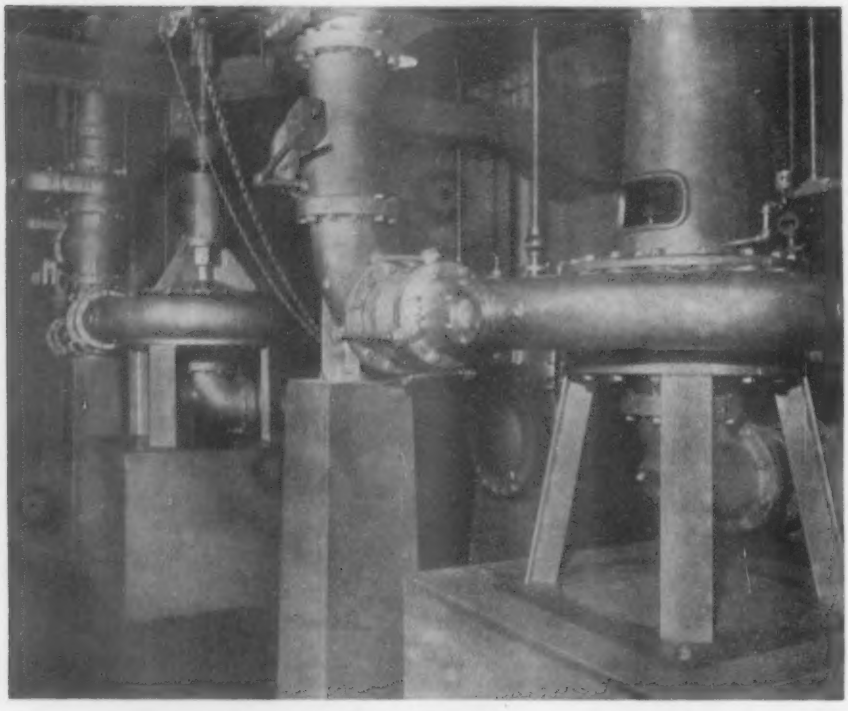
Here's the Answer to Corrosive Sewage

Armco ASBESTOS-BONDED Pipe was selected for this sewer because it will carry corrosive industrial sewage. Millions of asbestos fibers are bonded to the base metal by a zinc coating and sealed with a special bituminous saturant. The result is complete protection against severe corrosive conditions.

This, plus the flexible strength of corrugated metal design and tight, positive joints, adds up to years of trouble-free service. There is no danger of crushing, cracking, disjointing or malalignment. Quick, simple installation assures low first cost.

You can get Armco ASBESTOS-BONDED Pipe, or for limited headroom applications, ASBESTOS-BONDED Pipe-Arch in a wide range of sizes. Write us for full data. Armco Drainage & Metal Products, Inc., 3515 Curtis Street, Middletown, Ohio. Subsidiary of Armco Steel Corporation.

ARMCO ASBESTOS-BONDED SEWERS | ARMCO



YOU CAN RELY ON YOUR

FAIRBANKS-MORSE FIELD ENGINEER . . .

For trash pumps that won't clog!

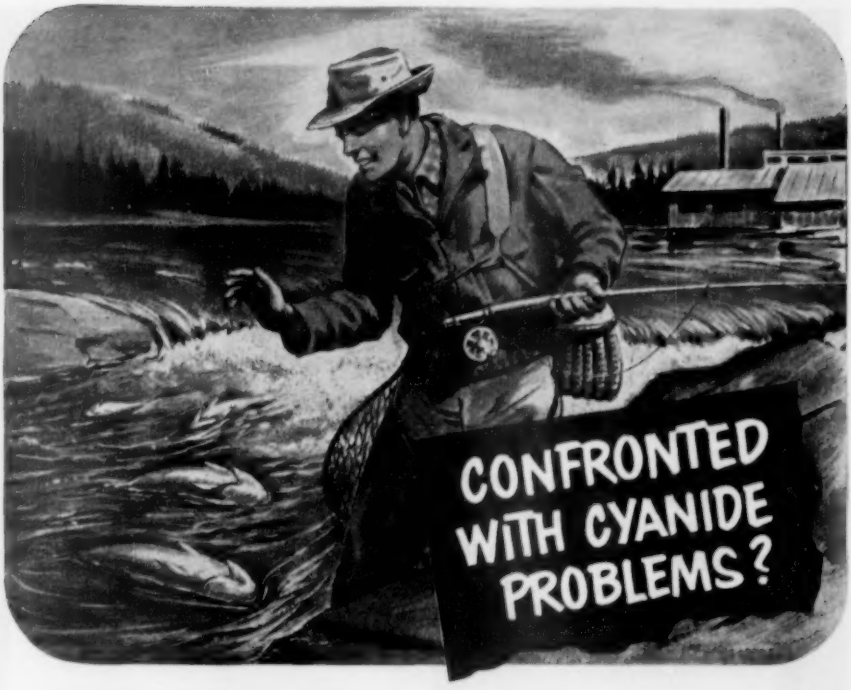
Would you like to cut maintenance costs on your sewage trash pumps 25% . . . 50% . . . even eliminate maintenance cost due to clogging? Call in your Fairbanks-Morse Field Engineer . . . have him give you all the facts on the Fairbanks-Morse Bladeless Impeller Pump . . . the pump that can't clog.

Your Fairbanks-Morse Field Engineer is a pump application specialist . . . can help you select the non-clog trash pump or other sewage plant or water supply pumps that exactly fit your requirements. Because he can recommend from the complete Fairbanks-Morse line, he has a type and size that will solve your problems . . . efficiently. Fairbanks, Morse & Co., Pump Sales Division, 3601 Kansas Avenue, Kansas City, Kansas.

FAIRBANKS-MORSE

a name worth remembering when you want the best

PUMPS • SCALES • DIESEL LOCOMOTIVES AND ENGINES • ELECTRICAL MACHINERY
RAIL CARS • HOME WATER SERVICE EQUIPMENT • MOWERS • MAGNETOS



Make use of the Unique Advantages of WELSBACH OZONE in Solving Them

The disposal of industrial wastes containing cyanide compounds is always a problem—because they are difficult to treat and must be reduced to very low limits.

That's why you should investigate the potential of Welsbach Ozone in solving these problems. Its efficiency, its economy and above all, its dependability provide an immediate answer. Investigations in the field, as well as laboratory research show that Welsbach Ozone is the ideal solution.

JUST CONSIDER THESE ADVANTAGES:

1. Cyanides are readily oxidized by ozone to products of negligible toxicity.
2. Overdoses of ozone can *not* result in toxic residuals in the treated waste. Therefore, close technical control over dosage is unnecessary and regular maintenance employees can operate the waste treatment plant.
3. Since ozone adds nothing but oxygen to the reaction, re-use or re-cycling of waste waters are often possible, resulting in substantial savings in volume of water used and in waste treatment cost.
4. A Welsbach Ozone plant can be operated on a batch or a continuous basis and can be made fully automatic. Ozonators and treatment vessels require very little space.
5. Welsbach Ozone is generated where it is used. No procurement problems. No freight, storage or materials handling expense.
6. Maintenance costs are negligible. And since the only raw materials needed are electricity and air or oxygen, operating costs are constant and predictable.

. . . but, most of all Welsbach Ozone is economical, convenient and dependable. Write today for information and, if you wish, indicate the nature of your problem. The Welsbach Corporation, Ozone Processes Division, 1500 Walnut Street, Philadelphia 2, Pa.

Investigate **WELSBACH OZONE**

LOW COST • DEPENDABLE

THE COILFILTER

Sanitary Engineers' Notebook

MEMO:

The COILFILTER is a continuous sludge dewatering machine. It consists of a sectionalized drum suspended in a filter vat, a roll standard which includes discharge and aligning rolls, two layers of stainless steel springs employed as filter media and a concentric agitator to keep sludge solids in suspension.

Sludge flows into the vat continuously so that about 25% of the drum area is normally submerged and wet cake is formed on the filter media in this area, due to a vacuum between the stainless steel drum face and the filter media. As the drum rotates, the wet cake emerges and air drawn through it further dewaters the cake.

Upon completion of the dewatering cycle the two layers of springs leave the drum and are separated from each other as the cake is discharged. The filter media is then washed by spray nozzles as it is automatically flexed and reapplied to the drum. Thus filter media entering the vat is always clean—there is no blinding or clogging—output remains constant.

Filter rates of 5 to 10 pounds of dry solids per square foot of filter area per hour are obtained with the COILFILTER, depending, of course, upon the type of sludge.

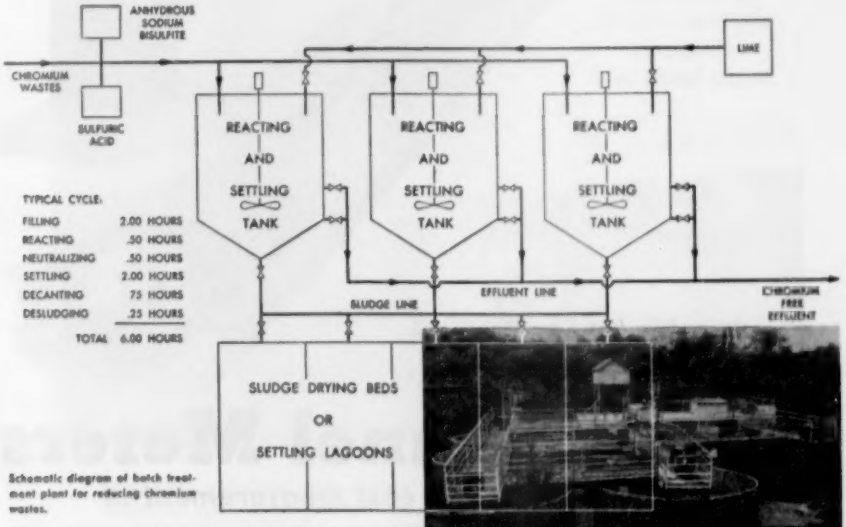
Write for bulletins No. 102 and 103

KOMLINE-SANDERSON ENGINEERING CORPORATION
PEAPACK, NEW JERSEY

Manufacturers of COILFILTER sludge vacuum filters

FOR EFFECTIVE, ECONOMICAL CHROMIUM WASTE DISPOSAL

...use General Chemical's Anhydrous Sodium Bisulfite



Schematic diagram of batch treatment plant for reducing chromium wastes.

Batch plant giving efficient removal of chromium waste at the Electrolux Corporation, Old Greenwich, Conn.

Toxic chromium wastes are simply yet effectively and economically treated and neutralized when you use General's Anhydrous Sodium Bisulfite. And it doesn't matter whether the volume to be treated is large or small! Learn the full facts and details . . . call General Chemical's nearest office for skilled assistance and helpful Technical Service in solving *your own* particular problem.

General Chemical has a broad, *practical* knowledge in planning chromium waste installations gained the country over. This knowledge is *yours*—without cost or obligation! For a start—get General Chemical's helpful *free* booklet on the treatment of chromium wastes. It offers sound information on the type of disposal system required, quantities of chemicals involved, operation and control of the system, etc.

GC Allied Chemical

Write for free booklet today!

GENERAL CHEMICAL DIVISION
ALLIED CHEMICAL & DYE CORPORATION
40 Rector Street, New York 6, N. Y.

Gentlemen:

☐ Please send me at no cost or obligation your free booklet, "Treatment of Chromium Waste Liquors with Anhydrous Sodium Bisulfite."

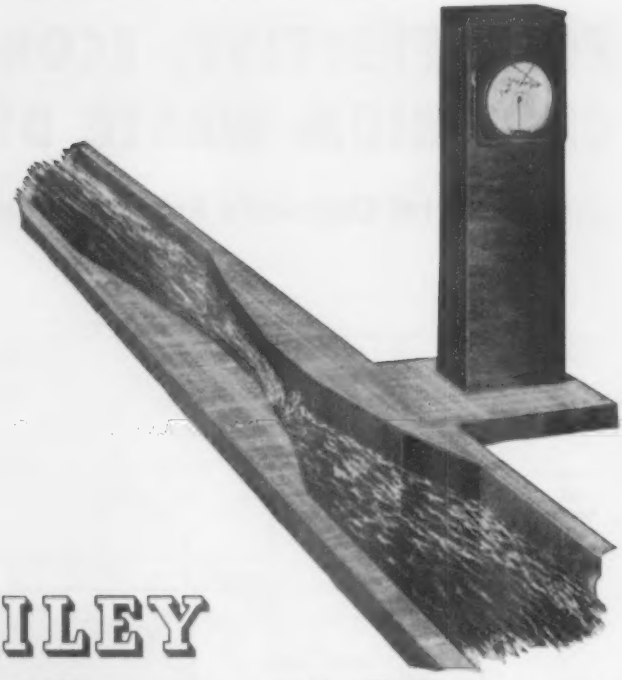
☐ Please have your representative call.

Name _____

Position _____

Company _____

Address _____ SW-7



BAILEY

Open Channel Meters

for trouble-free low cost measurement of

Sewage, Industrial Wastes, Sludge, Irrigation, Water Supply

Bailey Meters offer these advantages—

1. Easy to Install and Maintain
2. Retain Accuracy
3. Self Cleaning
4. Adjustable Capacities
5. Totalize Multiple Flows
6. Chemical Feed Control
7. Flow and Ratio Controls
8. Low Cost

For further information on how Bailey Meters can meet your needs, ask for Bulletin M22-5.

MU25

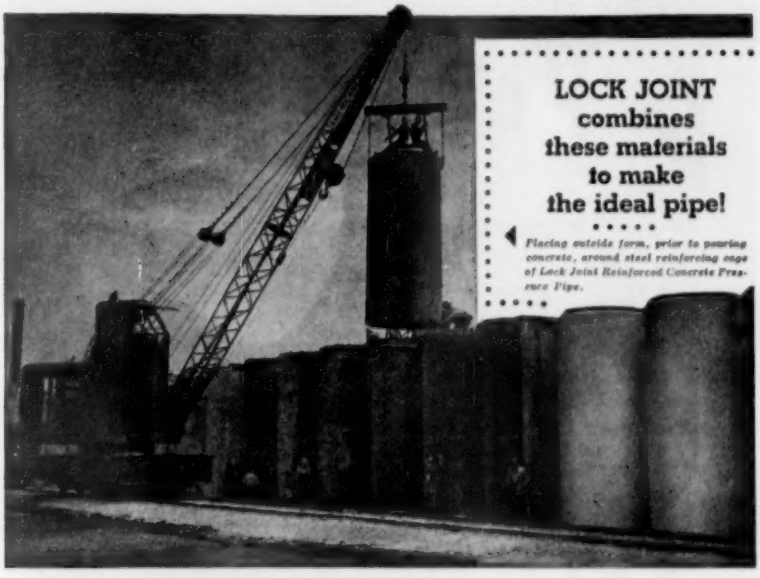
Bailey Meter Company

1066 Ivanhoe Road • Cleveland 10, Ohio

Meters and Controls for Sewage and Water

Venturi Tubes • Flumes • Weirs • Nozzles • Orifices • Direct Mechanical and Remotely Located Registers • Air-Operated, Electronic and Electric Controls

There's no substitute for CONCRETE and STEEL!



LOCK JOINT combines these materials to make the ideal pipe!

Placing outside form, prior to pouring concrete, around steel reinforcing cage of Lock Joint Reinforced Concrete Pressure Pipe.

CONCRETE, with its proven qualities of durability, non-corrosion, resistance to electrolytic action, and high compression strength is combined, by Lock Joint, with steel's toughness, resilience and high tensile strength to make a pipe that retains the best qualities of both—non tuberculance, high structural strength and long life with little or no maintenance. Dense concrete affords complete protection for the quality reinforcing steel. Both materials are carefully calculated to meet your pressure needs with a wide factor of safety. The Lock Joint Pipe Company's Rubber and Steel Joint is extremely watertight and, at the same time, flexible.

For superior strength, carrying characteristics and trouble-free operation, let Lock Joint supply your pipe needs in sizes 16" and larger.

LOCK JOINT PIPE COMPANY

Established 1905

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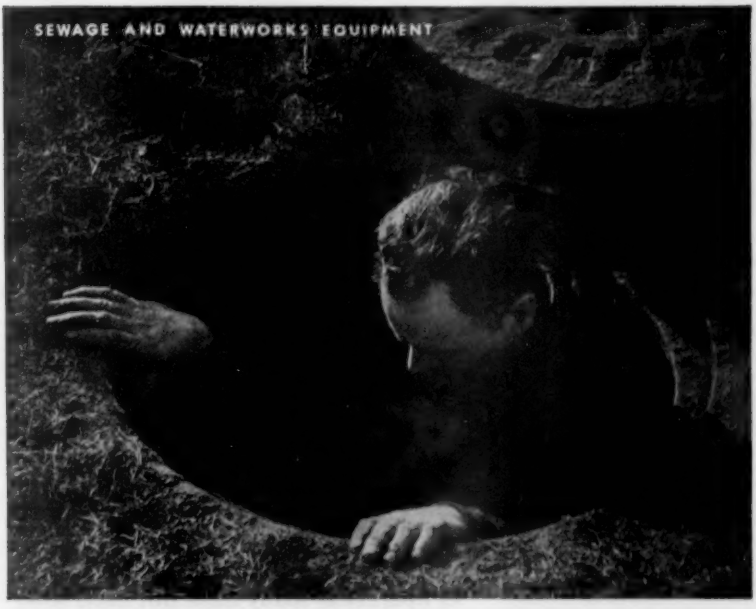

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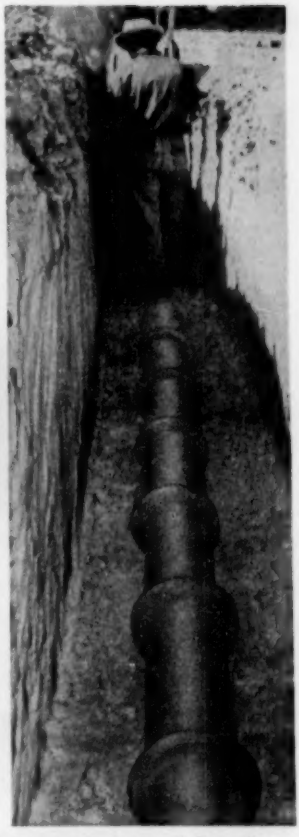

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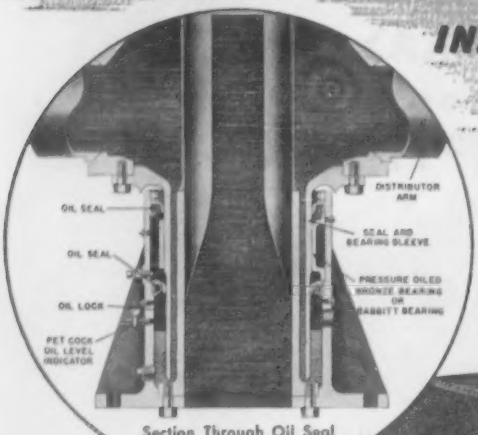

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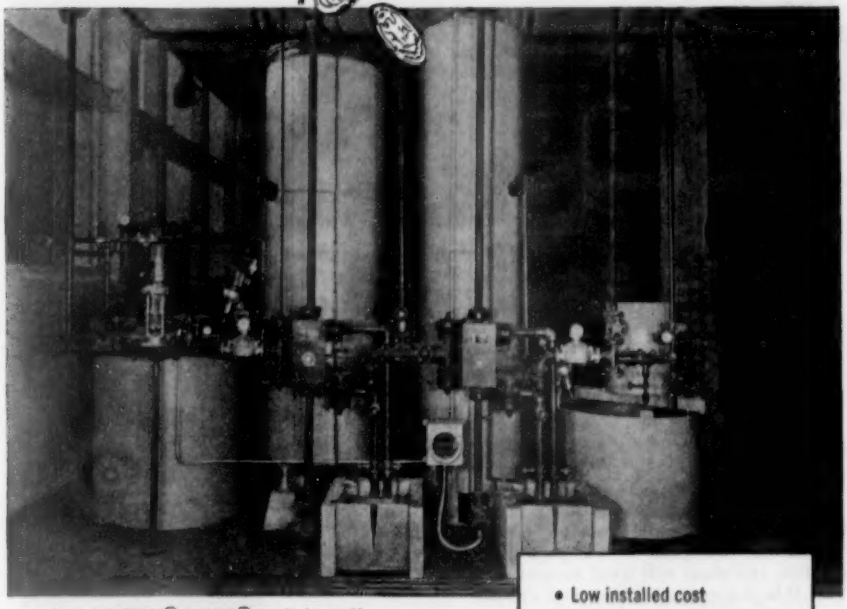

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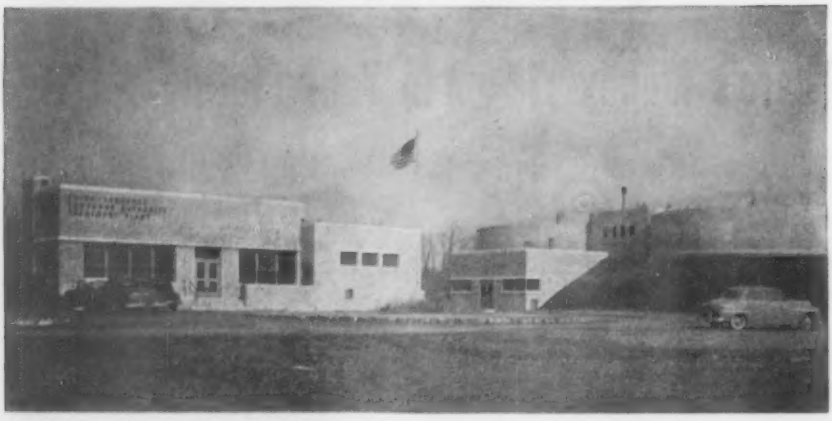
Right, digester control building and two 50′ digesters with PFT Floating Covers



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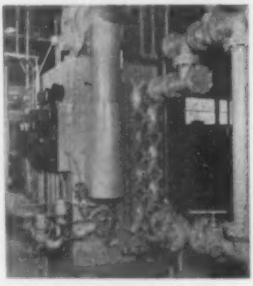

PFT Heater & Heat Exchanger unit (500,000 B.t.u. per hr.) in the digester control building.

A complete set of *PFT Gas Safety Equipment* for maximum protection against fires and explosions.

Both the plant and the sewerage system were designed for considerable future expansion. Congratulations to Ewing and Lawrence on their excellent new facilities and far sighted planning!

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 27 **July, 1955** **Number 7**

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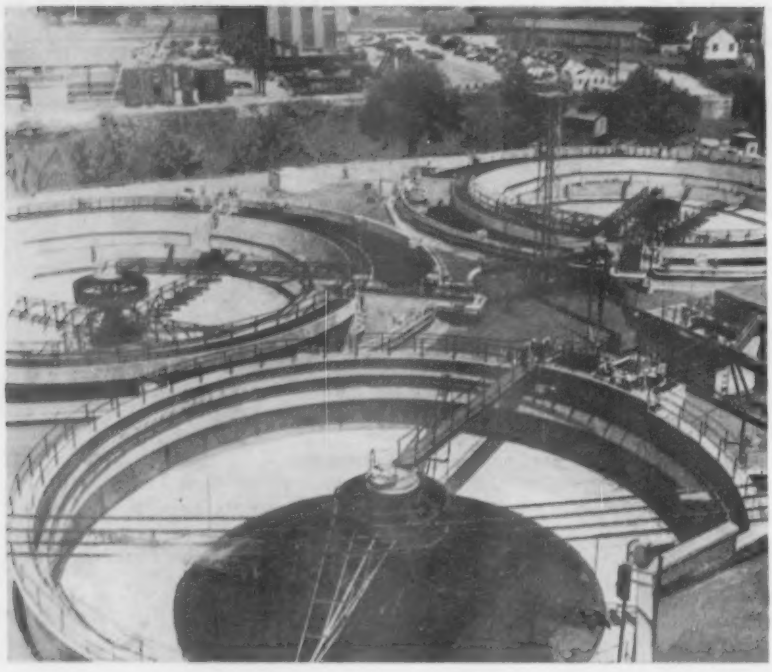

General view of the plant during final stages of construction. Dorr Primary Thickener is in foreground with Currie Clarifiers in rear.

Consulting Engineers: GIBBS & HILL, INC., New York, New York

West Virginia Pulp and Paper Company Pioneers New Waste Treatment Process

Dorr-Oliver Equipped Plant Sets Pattern for Industry

Covington, Va. Industrial waste treatment has taken a major step forward with the start-up of this new plant at West Virginia Pulp and Paper Company's Covington, Va., mill. A "first" for the alkaline pulping industry, it points the way toward a solution of these tough-to-handle wastes. Two years of pilot plant work went into the final design and the Covington mill's River Research Group worked closely with the National Council for Stream Improvement throughout all phases of the project. The firm of Weston, Eckenfelder and Hood was also called in to make an intensive round-the-clock analysis of pilot plant results.

The flowsheet as developed is unique. Basically it employs the activated sludge process, one of the standard methods for treating municipal sewage. A departure from standard practice is the addition of certain nutrients essential to the life of the bacteria which carry out the treatment process. Another is split treatment providing primary sedimentation for the portion of mill wastes containing solids and then parallel aeration and final sedimentation for the entire flow. A third is the use of complete instrumentation with one control panel governing the process and recording results.

Average treatment plant design is 16 MGD with a maximum capacity of 25 MGD. Major equipment units include a Dorr Primary Thickener and two Currie Clarifiers.* These latter units employ Dorr Final Clarifiers surrounded by annular aeration channels. In this way two distinct phases are carried out in a single unit. When the plant reaches full operation an estimated BOD reduction of 80-90% will be made in the mill effluent being discharged to the Jackson River.

Dorr-Oliver Incorporated, Stamford, Conn.

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Sewage Works

A CRITICAL APPRAISAL OF SEWAGE WORKS OPERATION AND DESIGN *

By Robert O. Sylvester

Associate Professor of Sanitary Engineering, University of Washington, Seattle, Wash.

Is research in the sewage field forming the basis for improved treatment plant design? If so, has the knowledge gained from research been utilized by the designing engineer?

All sewage research should have as its purpose the protection of the receiving waters through enlightened treatment plant and sewer design. This research must enlighten the designer; must present material he can understand, appreciate and use so that he will create a sewage collection and treatment system tailored to the owner's predetermined needs and ability to operate effectively. (Research of the basic type is of course an exception.) However, much research is presented in articles using mathematical, chemical and biological terminology that few Association members can read and understand.

The wide gap between theory and practice must be closed. The usual sewage treatment plant is designed in a set pattern to produce a product whose quality is very loosely defined. These set patterns are normally called primary treatment or secondary treatment. Is there a firm basis for specifying either primary or secondary treatment, or should the treatment lie somewhere between? There is little incentive for the designing engineer to follow research trends or to carefully examine the characteristics of the sewage to be treated or that of the receiving waters. All he has to do is design a plant in the set pattern that has been established and it will usually be accepted.

Any manufacturing operation, any utility plant, or any grouping of process machinery is designed to produce a definite product, which is carefully evaluated as to its quantity and quality. Why isn't this generally true in the process of waste treatment? Admittedly, the waste is a complex liquid having variable properties to be received by a water having variable characteristics and uses. No precise value can be set on either the characteristics of the effluent desired or on the quality of the receiving water that should be maintained. Nevertheless, we can and should approach a rigidity of values as has been done in other unit operations.

If the state regulatory agencies are to continue setting design requirements, they should make them more specific and require that the plant, to be acceptable, must produce an effluent having maximum permissible values of B.O.D., suspended solids, coliform bacteria, etc. This should give the designing engineer an incentive to keep up on research and perhaps do some of his own. It will cause all concerned to take a careful look at the liquid to be treated and at the receiving waters. It will also be an incentive to the treatment plant operator to operate his plant for a definite, rather than a very general,

* Presented at 1954 Annual Conference, Pacific Northwest Sewage and Industrial Wastes Assn.; Eugene, Ore.; Oct. 21–23, 1954.

objective. However, the application of refined theory finds little justification and a well-conceived treatment plant is of little value in those situations where the sewage collection system design, construction, or operation is faulty. This slighting of the collection system has resulted, in many instances, in the discharge of tremendous quantities of infiltrated ground water, uncontrolled industrial wastes, or heavy discharges of storm water that have made the waste treatment facilities largely inoperative.

The design, construction, inspection of construction and operation of a waste treatment plant is a specialized field and not one that should be considered fair game by just anyone interested therein, as is frequently the case. The designer must give the owner a plant tailored to his predetermined needs and ability to operate. Otherwise, why have individual plant designs—why not mass produce a given set of plans for both primary and secondary plants of various sizes, differing only by where pumps are placed.

The average sewage treatment plant design in Washington, from the author's observation, proceeds somewhat as follows. A municipality or industry is made aware of the necessity of constructing waste treatment facilities and engineering services are secured. The engineer subsequently determines, or he is informed, that the treatment shall be, for example, of the secondary or biological type. The usual procedure is for the designing engineer then to select various items of manufactured equipment, house them in a structure, interconnect them with pipes and controls, the sum total of which represents secondary treatment. He may design a very complex or a very simple treatment works, depending upon what he deems necessary, what equipment is available, or how much money can be secured for the project. Only too seldom does he ascertain, over a period of time before commencing his design, the characteristics of the sewage to be treated and the requirements of the receiving water for waste assimilation. Eventually the treatment plant is completed and placed in operation. If it is in a municipality, the chances are that no one connected with the administration knows much about the plant or how it should be operated. A feeling frequently exists that their obligation has been discharged because they built the treatment works that everyone was demanding and that it is situated in the lower end of town, across the railroad tracks where it belongs.

Will the operation of this treatment plant be considered satisfactory (a) when it presents a good appearance and has no odor; (b) when the mechanical, laboratory and electrical equipment is well maintained and functioning; (c) when the operational expense is low and no complaints regarding the plant have been registered; (d) when it is producing the highest quality effluent attainable; or (e) when the plant effluent is compatible with the receiving water quality that is desired? Is this plant effluent compatible with the receiving waters when it has a B.O.D. and suspended solids of either 10, 30, 50 or 70 p.p.m. and a coliform bacteria M.P.N. of 24, 240, 2,400, 24,000 or 240,000 per 100 ml? All of these effluent values may be possible of attainment, depending upon how the plant is operated. Does the average plant operator know what characteristics his effluent should have as maximum tolerable values or is it assumed that these are satisfactory if the chlorine residual is as prescribed and the operational control test record sheet has been dutifully prepared and submitted?

Study of Sewage Treatment Plant Operation

In the summer of 1953, the author was engaged by the Washington Pollution Control Commission to make a study of sewage treatment plant operation in the state. The purpose was to obtain an impartial view on such questions as: What factors contribute to either good or poor plant operation? What can be done to secure better operation? How might the Commission and the State Department of Health best function as state regulatory agencies in the field of sewage treatment? Of the 121 sewage treatment plants in the state (1953), 84 were visited and the plant operators, the responsible supervisory officials, or both, were interrogated, together with a brief inspection of the treatment plant. Most of the consulting engineers in the state engaged primarily in sewage works design were questioned in a similar fashion. Data were obtained on the plant design, construction and operational characteristics, qualifications of the operators, and the attitude and opinion of the operators and supervisory officials on various aspects of sewage treatment. There follows some of the information obtained in this study and interpretations thereof that might be of interest.

Construction Cost Data

Construction cost data were obtained from 64 of the plants visited. These construction costs were projected to 1952 costs using the *Engineering News-Record* Building Cost Index (1). These 64 plants had a total estimated 1952 building cost valuation of $15,727,000, or an average cost of $23,000 for each 1,000 design population. Using the plant design populations and the 1952 cost index of $23,000 per 1,000 design population, the total 1952 plant cost is about $20,300,000 for all of the 121 plants (1953) in the state. The investment in sewage collection systems is, of course, many times this amount.

Figure 1, illustrating the variation in construction costs for the 64 primary and secondary type treatment plants, shows that it is impossible to predict the cost of a treatment plant based on the population to be served. The cost of a plant of given size depends upon the complexity of treatment, amount of pumping involved, site limitations, quality of construction, amount of mechanical equipment employed, location within the state, and the number of contractors anxious for the opportunity of constructing the plant. In many instances it is believed that construction costs have been too high for the treatment required. They have been too high because of the plant design arrangement or because of the inclusion of many non-essential items. It is necessary that construction costs be kept as low as is practicable if cities and other agencies are to continue the treatment plant construction program and have sufficient money remaining for adequate treatment plant operation.

On a flow basis, construction costs (projected 1952) per million gallons of plant design capacity were as follows: less than 1,000 persons design capacity, secondary plants $510,000; 1,000 to 5,000 persons design capacity, primary plants $287,000, secondary $376,000; 5,000 to 10,000 persons, primary plants $114,000, secondary $223,000; 10,000 to 50,000 persons, primary plants $103,000, secondary plants $325,000. These figures should not be used without caution, as they were compiled from projected costs and from plant design capacities that may vary, depending upon one's interpretation of what design capacity includes.

Faults in Plant Construction

Some of the reported faults in plant construction are the result of poor design, but most of them appeared to

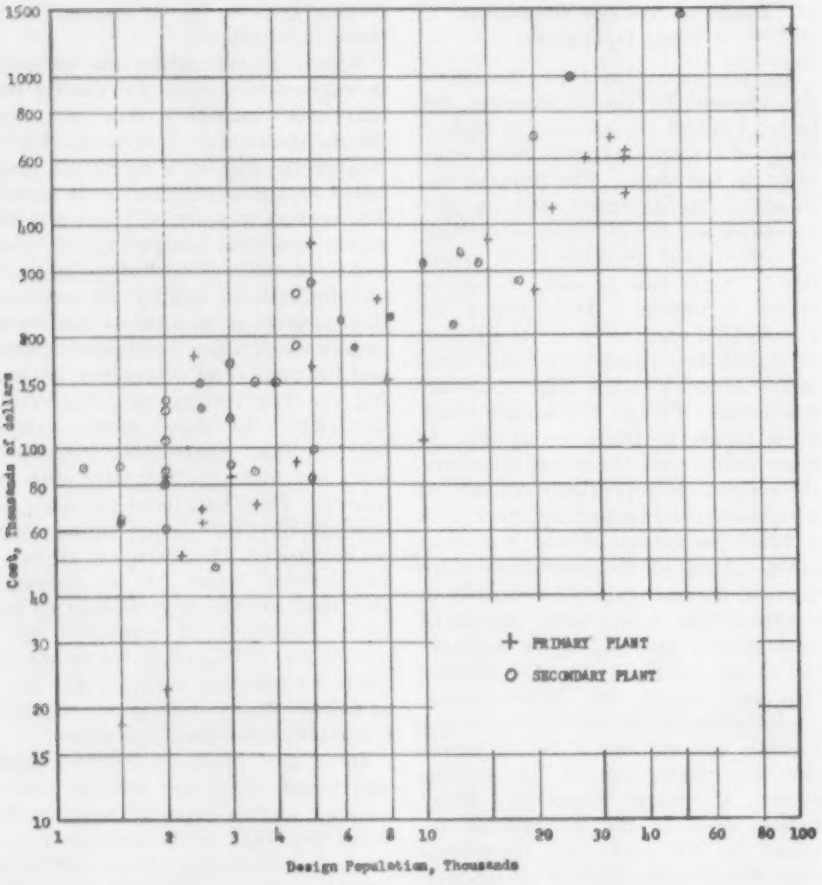

FIGURE 1.—Construction costs (projected to 1952) of treatment plants in the State of Washington.

be the result of poor workmanship and poor inspection at the time of construction. The faults reported are as follows:

1. High infiltration in sewer lines leading to the plant.
2. Cracks in concrete digester roofs, with resultant gas loss.
3. Cracks in concrete walls, ceilings and roofs.
4. Uneven or excessive backfill settlement, with resulting tilt and fracture in buildings and walks and broken pipelines.
5. Equipment improperly installed.
6. Floors slope away from instead of towards the drain.
7. Placing of improperly sized filter media.
8. Poor concrete work on floors and walls.
9. Painting over rust.
10. Debris left in pipes.
11. Failure to install valves shown in plans.
12. Poor pipe joints, resulting in leakage and flow stoppages.
13. Leakage around pipes where

they pass out of tanks filled with sewage or sludge.

Design Improvement Desired

Many of the design improvements desired should have been incorporated in the original plans. Others were deliberately left out of the original plans (and perhaps rightfully so) to reduce construction costs and still achieve a workable plant. Design improvements desired by the operators for their plants include:

1. Provision of adequate grit chambers.
2. Digesters should be heated and provided with sampling pipes and a stirring mechanism.
3. Design sludge hoppers in rectangular clarifiers so that sludge may be easily removed.
4. Avoid dead-water areas in channels, as they provide space for sludge and scum accumulation.
5. Provide adequate ventilation for trickling filters.
6. Avoid bends, where possible, in sludge lines.
7. Provide larger sludge recirculation pumps.
8. Provide drains on all tanks.
9. Make adequate provision for operation during high-water stages at point of effluent discharge.
10. Make sludge pump suction lines short, straight, with no high spots, and not too high above sludge hoppers.
11. Provide adequate digester and sludge drying capacity.
12. Provide adequate baffling in detention tanks.
13. Provide means of observing the sludge being pumped to the digesters.
14. Locate valves for ease in plant operation.
15. Locate flow measuring devices so they will accurately measure the sewage flow.
16. Design pump wet wells so that sludge will not accumulate.
17. Design with adequate allowance for industrial waste loads.
18. Carefully check the hydraulics of the plant.
19. Provide sludge pump switches at points where pumped sludge is being observed to minimize pumping of sewage into the digesters.
20. Provide unit by-passes.
21. Arrange treatment units so as to minimize walking and climbing required for plant operation.
22. Provide means for controlling the odor problem when there is no dissolved oxygen in the raw sewage.
23. Consider the odor problem in designing sludge concentration sumps.
24. Spend less money on automatic equipment and building spaces.
25. Use plug instead of gate valves whenever possible.
26. Anticipate ground-water uplift on buried tanks.
27. Provide sufficient and properly located valves.
28. Do not make laboratory tables long and narrow and do not place them in front of a window that faces the afternoon sun.
29. Determine the location of the ground-water table during all seasons of the year before locating sludge drying beds.
30. Provide separate valves on each sludge hopper drawoff line.
31. Provide more manholes in digester roofs, more points of entry for recirculated sludge and more points of supernatant drawoff.
32. If pipes must contain high spots, provide relief for air binding.
33. Hand-cleaned bar screens are not adequate where the entering sewage contains a large number of rags.
34. Provide for reversal of flow in Imhoff tanks.
35. Incorporation of features or units of a very old plant into the new plant design did not save money and makes for less efficient operation.
36. Provide more storm-water diversion capacity.

37. Cement-asbestos pipe is not strong enough for use around treatment plants.

38. Insulate digesters.

39. Submerged lift pumps are hard to service and repair.

40. Provide a positive head on the suction side of piston-type sludge pumps.

41. Avoid concrete slabs over sludge hoppers on rectangular clarifiers.

42. Do not bury gas piping inside concrete walls.

43. Arrange underground piping for accessibility and ease in cleaning.

44. Consider safety of the operator when designing the plant.

The Operators

There were some 188 people in Washington (1953) engaged in the operation of sewage treatment plants treating domestic sewage. Data were obtained regarding 151 operators in 82 plants. Of these 151 operators, only 11 had any prior experience with sewage treatment before being employed at their present plant. This is considered quite significant when one is appraising the status of operation. Sixty-three were employees of the plant owner before or after the plant was built and were assigned to operate the plant on a full-time or part-time basis. Few of those employed in plant operation have had any training or job experience (such as mechanic, machinist, electrician, biologist, chemist or plumber) that would correspond with the over-all job requirements of an operator of a modern treatment plant. Good operation is usually found in plants where the operators have been hired after applying for the job or where they have been hired because of their past experience. In plants where the operators have been assigned the job of operation, their attitude towards sewage plant operation ranges from one of keen interest to one of open dislike. Operators had been arbitrarily assigned the job of plant operation in nearly every case where the treatment plant was not being operated satisfactorily. Small communities obviously cannot afford the expense of full-time operation and must utilize their operators for other tasks. It is unwise, however, to have an $85,000 treatment plant operated by an incompetent or disinterested person just because this individual is already conveniently on the payroll.

Of the 84 plants visited, 49 were operated on a part-time basis, the operator having other duties for the remainder of his working day. He usually has a helper or two, sometimes none except in emergencies. The small town utility man is an unsung hero—his working day is a long one, he is called upon at all hours of the day and night for special tasks, and he is expected to be an expert in all utility operation.

Other data on the operators are as follows:

1. Average experience in plant operation was 3.4 years per operator.

2. Operators in only 23 of the 84 plants visited knew what it was costing to treat their waste waters.

3. In the group of 72 operators who had applied for voluntary certification, formal education averaged 11.2 years, ranging from one operator with 6 years of schooling to two with 17 years. The average age in this group was 43.5 years, with individual ages ranging from 22 to 66.

4. Operators in only 26 of the 84 plants knew what quality of effluent their plant should produce.

Treatment Plant Operation

Cost of Operation

Figure 2 illustrates the variation in yearly operating costs (1952) *versus* the population served for primary and secondary type plants in Washington. The approximate average operating costs for those plants regarded as hav-

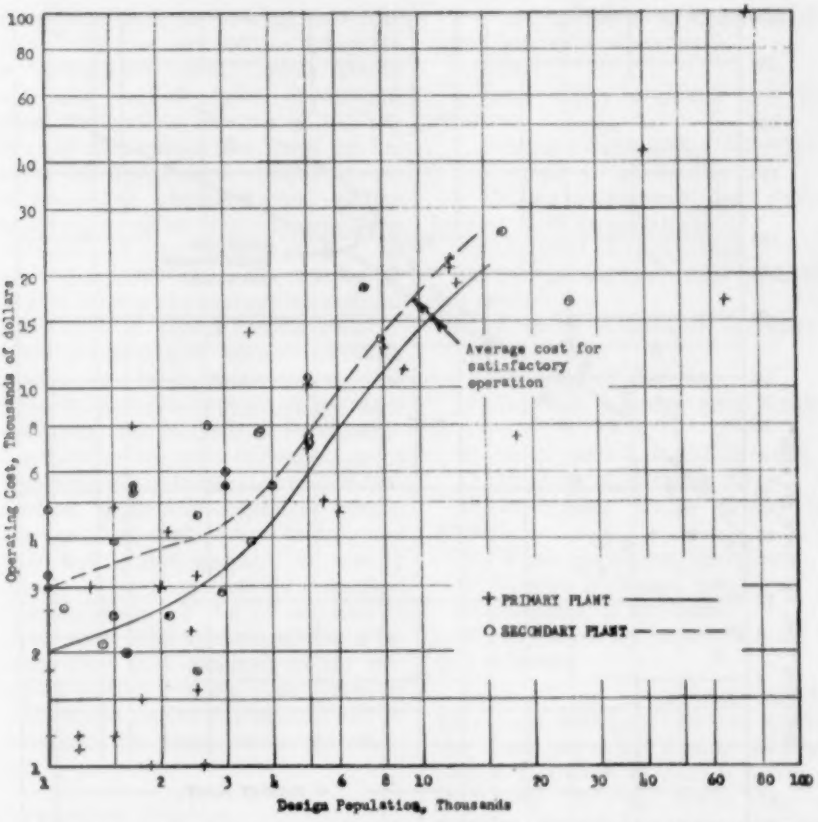

FIGURE 2.—Annual operating costs of treatment plants in the State of Washington.

ing satisfactory operation are shown up to about 10,000 population served. Treatment costs in general exceeded $2.00 per capita per year for less than 1,000 population served, declining as the population served increased to where plants serving more than 20,000 persons had treatment costs slightly exceeding $1.00 per capita per year. Treatment costs involving secondary treatment were about $500 per year more than for primary treatment where the population served was less than 1,000 and about $2,000 per year more for plants serving more than 6,000 population.

The charges various cities make against operation vary, with some cities charging everything possible to the operational costs and others charging very little of the true costs. Only 33 of the 84 locations visited had definite operational costs compiled. Operational costs at the other locations had to be compiled by adding up the various items of plant costs (such as labor, power, chlorine, repairs and maintenance, water, telephone, truck usage, billing, auxiliary fuel, chemicals, insurance, and any special site assessments).

On a million-gallon-daily flow basis, annual treatment costs for satisfactory treatment involving average treatment conditions were as follows: all plants less than 1,000 persons design

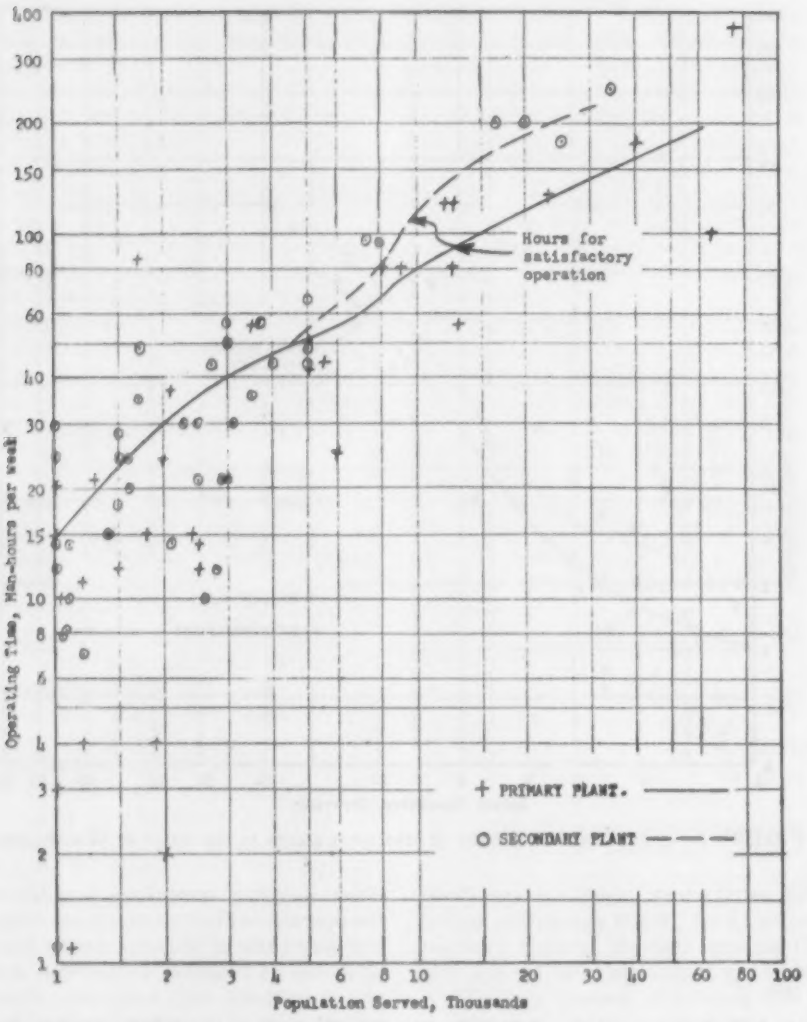

FIGURE 3.—Weekly operation time required for operation of treatment plants in the State of Washington.

capacity $10,000; 1,000 to 5,000 persons design capacity, $13,000 for primary plants and $13,800 for secondary plants; 5,000 to 10,000 persons, $4,000 for primary and $9,000 for secondary plants; 10,000 to 50,000 persons, primary $5,100 and secondary $7,800; over 50,000 persons, $3,200 for primary plants. These figures are subject to considerable error, since many of the plant design flows were difficult to obtain.

Time Spent on Operation

Figure 3 shows the time spent at the plants visited for normal operation in man-hours per week *versus* population served. One is immedi-

ately impressed, in viewing these figures, with the tremendous difference in operational effort. Some plants naturally require more operational time than others because of the nature of the wastes they treat or because of design and equipment deficiencies or characteristics. Time spent on operation is also frequently a reflection of the interest shown by supervisory officials. The curves of Figure 3 show the average operational time spent at plants having satisfactory operation with normal operating conditions. It is interesting to note from these curves that about the same operating time is spent in plants serving 4,000 or less persons, regardless of what type of treatment is employed (excluding single-unit treatment plants, such as those with Imhoff tanks), and that a full-time operator is usually employed for plants serving more than 3,000 persons. A few of the smaller cities show high operational times because they have assigned an old city utility employee to the plant where he will remain on the city payroll and be available for consultation on their utility problems.

Operational Troubles

Operating difficulties may be caused by ineptness or carelessness of the operator, by poor design, by faulty equipment or equipment installation, or by waste discharges into the sewer system unforeseen or not properly provided for at the time the plant was designed. In some instances these operating difficulties are inherent to the treatment of waste waters. Operational difficulties,* listed in order of times mentioned by the plant operators, were as follows:

1. Sludge pumping.
2. Sewage lift pump operation.
3. Getting sludge out of rectangular clarifiers.
4. Plant unable to properly handle heavy industrial waste loads.
5. Odors.
6. Sand and silt getting into the digesters.
7. Getting proper sludge digestion.
8. Keeping up pH in digester.
9. Making equipment for sludge heating work automatically.
10. Clogging of sludge lines.
11. Oil carried into plant with the raw sewage.
12. Keeping chlorinator operative.
13. Vandalism.
14. Foaming of digester.
15. Inability to control scum blanket in digester.
16. Scum control in Imhoff tanks.
17. Ponding of trickling filters.
18. Inadequate sludge drying facilities.
19. Waste gas burner operation.
20. Timing of sludge pumps.
21. Clogging of gas lines.
22. Deposition of organic matter in grit collectors.

Some of the operational troubles have been extremely serious in that they have cost or are costing the plant owners thousands of dollars yearly or they have made the entire plant or portions thereof inoperative for prolonged periods of time. For example, one plant had to employ an extra full-time operator because of influent channel screen clogging. Another plant was shut down and by-passed for several weeks until special help was able to unload the digesters of their accumulation of sand and silt. One small town seriously neglected its treatment plant for several years. The plant became inoperative and the raw sewage was discharged directly to the river. When the town became aware of the situation, it had to spend more than $1,000 to replace and repair inoperative equipment. Other cities have spent $500 to $1,000 yearly for auxiliary digester heating fuel that would be unnecessary if the digester was operating properly.

* Many of these difficulties are related in that one is the cause of another.

Factors Affecting Operation

Satisfactory functioning of domestic sewage and other waste treatment plants is related to many factors in addition to the operator himself. It is related to the general knowledge and interest of the public and owners on the purpose of the plant and its function; the planning that went into the plant; the extent and adequacy of help and advice rendered by interested state agencies; the quality of construction and equipment; and a continuing desire on the part of the treatment plant owners to fulfill their waste treatment obligation to society. Pollution abatement has not been achieved with construction of the treatment plant unless the plant is continuously and effectively operated.

It was observed during the survey that those plants with seemingly satisfactory operation had most of the following:

1. City or supervisory officials that take an active interest in the plant.
2. A competent operator.
3. An operator interested in sewage treatment.
4. Adequate time allotted for operation.
5. A well designed and constructed plant.
6. A well designed and constructed sewer system.
7. An operating goal.
8. Adequate advice and assistance from state agencies.
9. Equipment of sturdy and proper characteristics for its function.
10. Interest in the plant on the part of the local citizenry.

Laboratory Operational Control Tests

The state regulatory agencies have specified certain laboratory operational control tests (2) that should be performed on a schedule according to the size and complexity of the treatment plant. These laboratory test results are recorded by the plant operators on record sheets furnished by the state. The purpose of these records is to enable the plant owner to keep a record of his plant's performance and sewage characteristics, to anticipate operational trouble when control test results depart from normal, to officially record plant effluent characteristics with the state, and to enable the state to point out operational deficiencies based on the plant laboratory record.

The real value of the operational tests to the plant operator is, of course, dependent upon his understanding the use and significance of the tests. According to the operators, the laboratory tests of operational value and their utilization in plant operation depends upon their own particular operational problems and plant characteristics. Within the limit of available time, those operators having an understanding of the laboratory control tests performed all they could find time for, whereas those unfamiliar with the tests ran as few as possible, or none. Nearly every operator found the chlorine residual test of value (those who didn't were unable to get residuals because of design limitations, strong wastes, or limitations on quantity used because of cost).

Of 82 plant operators questioned, 27 felt that nearly all of the control tests were of value in their plants, 7 thought none were other than chlorine residual, and 12 did not know what tests were of value. The remaining 36 held the following tests to be of most value to them: Thirteen valued settleable solids, 15 sewage pH, 30 digester pH, 5 digester alkalinity, 8 dissolved oxygen, and 2 sludge characteristics. Some of the operators would have run more tests if they had more time and available equipment; others did not use a fraction of the laboratory equipment available to them. Several of the operators, who had been operating for a number of years, stated that they

could operate their plant satisfactorily just by the appearance of the sewage as it progressed through the plant and that the only necessary tests were for chlorine residual and an occasional digester test.

Operational Criteria

The principal deficiency in the entire operational program of the state has been the lack of any definite operational criteria. Of primary concern to the state is the quality of the plant effluent that is discharged to its watercourses. In no instance had this required effluent quality been clearly and completely established. The establishment of an operational goal would be an incentive to the operator and the owner to watch their operation from the standpoint of what effect it is having on the receiving waters, rather than just on its appearance, freedom from odors, lack of operational troubles, and economy of operation (all of which are, of course, important). If these stipulated effluent characteristics are not being achieved, there is then the incentive for the operator to run control tests to find out why, and there is a definite basis for the state to ask for better plant operation.

Interest of City or Other Officials

Since the attitude and performance of a supervised employee frequently reflects the attitude and interest of his supervisors, data were collected on each visitation as to the general interest of the supervisory officials. Interest and attitudes are summarized as follows: Interest good, 19; interest fair, 34; interest slight, 22; and interest poor, 8. Many operators reported that the elective officials had never visited the plant after it was placed in operation and that the only time it was mentioned was when money was needed for some item of repair.

Educational Programs

Education of the general public and municipal officials as to the need for pollution control has been very good. In no instance during the survey was there any question as to the need for, or desirability of having a treatment plant. A need exists for extension of the educational program past the point of a general approval of sewage treatment to an awareness of what sewage treatment involves, the complexity of a modern treatment plant, the skill required for its proper operation, and the need of continuously and effectively operating the plant.

One-half, or 36, of the individual written examinations that had been taken for voluntary certification in Washington were reviewed to find where the greatest weaknesses have been in the educational programs for operators (programs such as short

TABLE I.—Summary of Voluntary Certification Written Examination Review

Item	Questions		Answers		
	No.	Times Given	Right (%)	Wrong (%)	Unanswered (%)
Question subject matter:					
Sedimentation and digestion	24	864	74.6	24.2	1.2
Laboratory	12	432	65.7	33.4	0.9
Trickling Filter	13	416	70.8	28.4	0.8
Question type:					
Practical	14	488	81.7	18.0	0.3
Theoretical	25	876	68.4	31.5	0.06
Arithmetical	10	348	28.2	30.8	41.0

courses and on the job training). This written examination consisted of 50 questions on sedimentation and digestion, 30 on the laboratory, and 30 on trickling filters, or a total of 110 questions. Of these 110 questions, 49 were selected for the review, to include representative questions on theory, practical operation, and arithmetic. Table I shows the performance on these questions. It is evident that the operators must be given more education on theory or the reasons for what they are doing, a better conception of their laboratory procedures, and more training in solving simple arithmetical problems that pertain to plant operation.

Recommendations

For Plant Owners

1. Job classifications and job requirements should be established by the treatment plant owners for operators working full-time on plant operation.

2. Operators for new treatment plants should be secured, where possible, from among those who are presently demonstrating their ability to operate a similar plant in another locality.

3. Sewage treatment plant operators should be given a job status commensurate with that given other utility employees.

4. It is desirable that operators for new plants be hired when construction on the plant commences and that they be given a job at the scene of construction.

5. Supervisors of sewage systems should be selected, whenever possible, from those who have a knowledge of and interest in this field. It is desirable in the larger cities that a position be created for this supervision.

6. Municipalities should officially recognize the position of "sewer" or "sewerage superintendent." If the supervisor is the water superintendent, he should have the official title of "water and sewerage superintendent," not just water superintendent.

7. Operators should be encouraged to avail themselves of all opportunities afforded for self-improvement and the plant owner should make it possible for the operator to avail himself of these opportunities.

8. A record of all plant operational costs should be kept, preferably by the operator. The operator must know what each phase of the plant operation is costing.

9. Since the first cost, operational costs and effectiveness of operation are most important, it is advisable that the future plant owner exercise care and judgment in the selection of his designing engineer. An engineer is not competent to design a treatment plant just because he is an engineer. The consulting engineer selected should have had considerable experience and education in the field of sanitary engineering. Past clients of a prospective consultant should be interrogated. The consultant who proposes to accomplish the design at the lowest fee is not necessarily the one to retain.

10. Cities should regulate by ordinance those wastes discharged to its sewers that are detrimental to plant operation or destructive to the sewage collection system.

11. Plant owners should notify the state regulatory agency when it is necessary to by-pass any part of a treatment plant, or when they have an inexperienced man on the job who needs help.

12. Community interest in the plant can be secured by inviting school classes and various service organizations on periodic tours of the plant and by locating new plants in or near populated areas where community interest will necessarily develop therein.

13. Where several small sewage treatment plants are located in close proximity, it is suggested that the plant owners consider the advisability

of jointly hiring an experienced operator or operators to run their treatment plants for them. The owners of small treatment plants located near a large municipal plant might contract with that municipality for operation of their small plant on a part-time basis.

For State Regulatory Agencies

1. Establish water quality criteria.

2. Encourage municipal and industrial supervisory personnel to attend short schools and association meetings.

3. Carry the pollution abatement educational program one step further to the general public by stressing the need for continuous and effective operation.

4. Organize and assist, if necessary, a voluntary program of operator certification.

5. Encourage periodic meetings of operators on a regional basis for operator education.

6. Short schools should have an established curriculum with a point of termination and should not be an indefinite series of schools as far as the operator is concerned. They should stress learning by doing and by demonstration, rather than by lectures.

7. Plans and specifications should be reviewed in greater detail by the regulatory agencies. (This, surprisingly enough, was the majority opinion of the consulting engineers interrogated.) Emphasis should be placed on effectiveness, simplicity, economy, and ease of operation, as well as on economy of construction. Items pertaining to economy of construction and operation should be called to the attention of the owner for decision on whether or not they should be included in the design.

8. In specifying the required treatment for a new waste treatment plant, the state regulatory agency should specify the effluent characteristics desired (maximum permissible values), rather than the degree of treatment required.

9. The state regulatory agency should issue each treatment plant a document to be posted at the plant in a conspicuous place. This document would list the design standards for the plant and give the state's requirement on effluent quality for the plant.

10. Arrangements should be made for the central preparation of laboratory reagent solutions that could be purchased by each plant owner as needed.

11. Operational record forms should be prepared by each plant owner (with assistance by the state when necessary) to fit the needs of the particular plant. A summary of these records should be submitted each month to the state regulatory agency on a form supplied by the agency.

12. On-the-job training for part-time or for new operators should stress operation by visual control methods and by the use of a written operational routine furnished each operator. Utilization of laboratory tests for new plant operational control should be kept to a minimum. Additional laboratory work should be recommended only when the need for same is clearly evident and then only when the operator will have the time and ability to perform and interpret these tests. There exists a need for a general operation manual on sewage treatment.

13. More information should be obtained on the quality of plant effluents and on the change in receiving water quality that has been effected through waste treatment measures.

For Consulting Engineers

1. "As-built" plans given the owner should carry a special sheet listing the plant design standards and equipment characteristics.

2. Written instructions for plant operation should be given the owner

prior to the plant being placed in operation.

3. The designing engineer or his representative should assist in placing the treatment plant in operation and he should remain at the plant, or revisit it as necessary, until all of its units are in proper operation.

4. Inspectors for sewer system and sewage treatment plant construction should be competent and should be on the job during the entire period of construction.

5. Preliminary budgets given prospective plant owners should include a fair representation of expected operating costs, together with the actual time that should be spent on operation.

6. Sewage treatment plants should be designed for economy of construction and operation, compatible with a capacity for effective sewage treatment. Automatic equipment that will not result in an actual saving in operational costs should be omitted. This pertains in particular to automatic equipment that requires frequent adjustments and repairs.

7. Prior to designing a treatment plant, adequate information on the characteristics and quantity of wastes to be treated should be obtained.

Acknowledgments

The study reported herein (3) was made for E. F. Eldridge, Director and Chief Engineer, Washington Pollution Control Commission. The writer gratefully acknowledges the information and time given by the sewage treatment plant operators, municipal officials, supervisory personnel, consulting engineers, sewer district commissioners, and the staffs of the State Health Department and the Washington Pollution Control Commission.

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FEDERAL SANITARY ENGINEERS ORGANIZE

Sanitary engineers in federal service can get together in a new organization known as the Conference of Federal Sanitary Engineers. Gordon McCallum, head of the water pollution control program of the U. S. Public Health Service, is president pro-tem.

Eligible for membership are sanitary engineers on active duty as commissioned officers with the Army, Navy, Air Force, Public Health Service, or employed as civilians by any federal department or agency. Special memberships are available to inactive reserve officers and former employees.

Meetings and cooperation with existing technical and professional societies are objectives of the conference. In addition, it will provide a "home" for federal sanitary engineers with mutual interests.

Information and membership applications may be obtained from Lt. Colonel Alvin Meyer, Secretary, 1701 South 78th St., Omaha 6, Nebraska.

TREATMENT OF SEWAGE PLANT EFFLUENT FOR INDUSTRIAL RE-USE *

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More efficient use of natural water resources is rapidly becoming a matter, not of simple economics, but of necessity. Important steps have been taken in this direction by many basic industries, particularly in the paper, steel, and petroleum refinery fields. These industries have found it practicable to recycle large volumes of water, thereby reducing their requirement from external sources. While steps of this sort can be expected to continue, the rapid growth of industry requires the constant addition of new water sources to meet such demands.

One practical and substantial source for additional industrial water supplies is the effluent from municipal sewage treatment plants. The purpose of this paper is to indicate current developments and factors involved in the design of equipment for treatment of sewage plant effluent for re-use in industrial processes and boiler feed applications.

Applications for re-use of sewage plant effluent were reviewed before the Federation at a joint meeting with the American Water Works Association in 1947 (1)(2). At that time it was felt that this source for industrial water would assume increasing importance in supplementing ground- and surface-water supplies in areas where the cost of reclamation compared favorably with the cost of development of alternate new sources.

Such re-use has not developed to the extent then anticipated. In spite of the tremendous expansion in industry since that time, and an increasing water shortage in many key industrial areas, this large reservoir of usable water has remained virtually untapped. This is true even though the quality of such water available has improved because of modernizing of sewage treatment plants during the same period.

In large part, the reason for this is a lack of recognition by industrial managers and their engineering advisors that this water source is available and can be satisfactorily purified for use by industry. There have been other hurdles, including difficulty of negotiating contracts equitable to both municipalities and industrial users for supply of effluent, certain technical problems which need further study, and, not least important, an esthetic reluctance to accept such supplies as a potential source of water for any purpose.

Applications for Re-Use of Effluent

A number of applications for sewage plant re-use have been cited in the literature.

For example, Wolman (1) discussed the design and performance of a treatment plant for purification of sewage plant effluent, subsequently used in steel mill processing operations, at a rate of about 65 m.g.d. A conventional clarifying plant was designed, employing flash-mixing, flocculation and 90-min. settling. The chemical treatment consisted of alum coagulation along with chlorination. The sewage plant effluent after clarification averaged 5 to 10 p.p.m. of turbidity with negligible *B. coli*. Operating

* Presented at 27th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Oct. 11–14, 1954.

costs, exclusive of interest and amortization, were given at $0.0173 per 1,000 gal., including pumping costs. The most serious problem reported at this plant was the presence of high concentrations of chlorides due to large amounts of industrial wastes fed to the sewage treatment plant.

Veatch (2) discussed the use of sewage plant effluent by various industrial users, including railroads and refineries.

Greenberg and Gotaas (3) discussed the use of sewage plant effluent for replenishment of ground-water supplies in California. Gotaas *et al.* (4) also reported more recent work in Los Angeles County on spreading and percolation for reclamation. The Kaiser Steel Company at Fontana, Calif. (5) has for many years been treating and re-using the effluent from their own sewage plant for quenching slag as well as for general industrial purposes, washing, etc. As early as 1935 a survey showed there were 135 localities in 18 states where treated sewage was used for various purposes. Of the uses classified in this report, 124 involved agricultural application (6).

McCormick and Wetzel (7) discussed the design and operation of a hot process plant which treats sewage plant effluent and processes a satisfactory supply for boiler feed water. More recently, arrangements have been made by industry with municipalities in Ventura, Calif., as well as in Texas and New Mexico (8).

Effluent from a properly operated secondary treatment plant may be superior for many applications to available surface supplies in the same area. In fact, in many parts of the United States the water supply for all purposes, especially during periods of low river flow, is reclaimed water from communities and industry upstream. It would appear, therefore, that the major factor involved in wider application of effluent reclamation is a realization by industrial managers and plant engineers of the inherent advantages of this use and proper evaluation of the economic and technical factors.

Factors Influencing Decision on Effluent Re-Use

Veatch (2) lists three conditions necessary for practical re-use of sewage plant effluent by industry, as follows:

1. There must be a local industry which needs water for processes not involving public health.
2. The sewage treatment plant must be large enough to supply these requirements.
3. Costs for processing, including transporting to the point of use, must be less than the cost of alternate supplies.

These conditions might be modified slightly by adding a fourth requirement:

4. The sewage treatment plant can deliver a reasonably consistent quality of water suitable for re-use by the particular industry.

Need for Water

The greatest demand for water by industry is for cooling water of all kinds. This single broad category exceeds all other industrial uses, most basic industries using tremendous amounts of water for this purpose alone (9). Where such industries are located in dry areas, study of possible re-use should always be considered.

Available Supply

In most cases, the volume of reusable water available from the sewage treatment plant is greater than the potential demand from the industry or industries needing this water. In fact, it has been suggested that it would be economical for the using industry to divert flow for re-use only during those periods when quality is highest (that is, at night), thereby reducing

chemical costs (10). These operating savings may be important enough to justify increased storage capacity for the reclaimed water.

Costs of Reclamation

Developing cost estimates for reclaimed water is an engineering problem requiring competent study and evaluation. Where the point of take-off of effluent is directly at the sewage treatment plant, municipalities have generally found it desirable to enter into a contract which establishes a service charge based on quantities made available, just as is done for potable water service. Such a contract is advantageous to the industrial user in providing time necessary to amortize capital equipment, and to secure co-operative effort to eliminate or minimize objectionable industrial waste discharges which may affect the operation of the sewage treatment plant. This is especially true with small municipalities where the potential user may contribute the major source of waste handled at the municipal plant.

Due to the complex nature of constituents which may be present in such sewage plant effluents, experience has shown that chemical costs can only be obtained from properly directed laboratory and pilot plant work. The designer of equipment for reclamation must provide chemical feed equipment, not for optimum chemical conditions, but for maximum foreseeable conditions of chemical demand. Flexibility in the design, number, and type of chemical feeders, as well as chemicals used, is required to assure dependable operation. Usually, the extent of preliminary laboratory and pilot plant work performed depends upon the anticipated use of the reclaimed water and the capital expenditure involved. A general rule should be to do more work, rather than less, during the engineering phase of the development in order to assure the most economical and dependable design.

Wherever sewage plant effluent can be used without further treatment, as in many applications involving once-through cooling systems, and particularly where such effluent is obtained from a modern well-operated activated sludge treatment plant, no further equipment costs are involved. However, if additional treatment of such sewage effluent is required to reduce color, B.O.D., and suspended solids, it should be recognized that such equipment can provide the dual function of clarifying and reclaiming the water, as well as preparing it for industrial re-use by softening, pH correction, and so forth. Even where alternate sources to sewage plant effluent are available the same basic equipment frequently may be required for proper water conditioning.

Effluent Satisfactory for Re-Use

Another factor influencing the decision on use of reclaimed water is the adequacy of facilities at the sewage treatment plant proper. Many communities are faced with treatment plants outmoded by recent population growths or industrial relocations. As a result, quality of effluent available to the using plant may vary widely from season to season or even from hour to hour. Depending again on the intended use, these variations may place a burden on the industrial facility to maintain required quality.

Where the sewage treatment plant is handling sewage primarily of domestic origin, the treatment control can usually be held within reasonable limits with proper plant design. In a majority of cases, especially in those areas where effluent re-use is likely to be considered, the population equivalent from industrial waste is likely to be the major contributor to the burden on the sewage treatment plant. The effect of such wastes, especially those which interfere with precipitation or biological oxidation, should be carefully considered. In some instances,

for example where mineral salts from industrial waste are present, it may be practical to work out a plan for segregating some wastes for separate treatment.

For most process applications, some further reduction in suspended solids, plus clarifying and decolorizing, are required to produce a satisfactory influent. Both conventional clarification and upflow sludge contact-type clarifiers have been found effective for this purpose. The latter have particular advantages for industrial plants where space considerations are important, and may be less expensive on an installed cost basis.

Factors Involved in Design

Characteristics of Sewage Plant Effluent

In terms of applicability of effluent for re-use, sewage plants can be divided into three broad categories, as follows:

1. Primary treatment.
2. Primary treatment plus trickling filters.
3. Primary treatment plus activated sludge.

Table I shows typical analyses of sewage plant effluent from a number of plants taken from published operating reports. The suspended solids content as well as the B.O.D. content in primary treatment effluent can be rather high. This is true with domestic sewage, but more particularly when the percentage of industrial waste is high. The addition of trickling filters or activated sludge treatment to the primary plant substantially reduces suspended solids as well as B.O.D. Although not indicated in Table I, the presence of significant amounts of synthetic detergents, as well as high mineral solids, substantially affects the possible application of sewage plant effluent to industrial water requirements.

TABLE I.—Typical Analyses of Sewage Plant Effluents

Plant	Primary Domestic		High Industrial Wastes	
	Susp. Solids (p.p.m.)	B.O.D. (p.p.m.)	Susp. Solids (p.p.m.)	B.O.D. (p.p.m.)
(*a*) Primary Treatment Only				
A	72	82	108	78
B	70	60	115	74
C	80	105	93	124
(*b*) Trickling Filter				
D	34	33	62	54
E	28	18	45	79
F	36	27	42	36
(*c*) Activated Sludge				
G	13	13	12	5
H	23	40	40	24
I	10	3	12	10

Effect of Various Constituents on Re-Use Application

There are five main differences between most sewage plant effluents and typical surface supplies, as follows:

1. Higher color.
2. Higher nitrogenous content.
3. Higher B.O.D. content.
4. Total dissolved solids usually higher than the available surface or well-water supply.
5. Presence of phosphates.

The presence of organic coloring compounds in raw-water supplies makes treatment necessary for removal of color together with other suspended matter in order to avoid formation of slimes, organic coatings, and, in the case of boiler feed water, substantial foaming and priming in the boiler.

The nitrogenous material in sewage plant effluent, of the albuminoid type, is usually substantially reduced by simple coagulation. The soluble nitrite and nitrate salts are unaffected by the usual coagulant chemicals and

treatment. These dissolved nitrogen mineral compounds are not usually troublesome in cooling-water application and in most boiler applications. However, nitrogenous compounds in boiler feed water in the reduced form, as ammonia or the ammonium ion ($NH4^+$), concentrate in the boiler salines and are distilled off at a high pH as ammonia, which redissolves in condensed steam and causes attack wherever copper or copper alloys are present.

The B.O.D. content of sewage plant effluent, and its equivalent organic matter concentration, can be a troublesome factor in re-use operation. Most cooling-water treatment processes require the absence of organic materials which can lead to pitting and localized attack on metallic surfaces. Also, organic matter in a cooling-water system inevitably means the possibility of "run-away" slimes and algae problems, with their attendant outages for maintenance and removal. It is the objective of the design engineer to make certain that reduction of B.O.D. to a manageable concentration is obtained in the water treating plant.

The effect of synthetic detergents on the operation of sewage treatment plants has been discussed at some length (11). Aside from possible interference in the normal operation of sewage treatment equipment, such detergents, in significant concentrations, may affect both cooling-water treatment and boiler-water treatment. It should be pointed out, however, that where difficulties have occurred in the field, the concentration of synthetic detergents in the treated water has been abnormally high.

With modern cooling-water treatment processes, such as low pH, high metaphosphate, or combination phosphate-chromate treatments, the presence of somewhat higher dissolved solids in recirculating cooling-water systems is frequently not serious. Wherever such higher dissolved solids treated effluent is to be used as makeup for higher pressure boilers, careful consideration and evaluation by internal treatment engineers must be given to the effect of such higher total dissolved solids on blowdown, potential scale formation and carry-over conditions.

Determining Proper Treatment

The most valuable tool for determining conditions required to produce an acceptable quality of water in the using plant is a well-organized series of jar tests. Techniques involved in such tests are not new, but still require substantial skill and experience, not only in planning and running the tests, but also in translating results to plant-scale equipment.

Treatment of sewage plant effluent requires even more careful laboratory test work than do surface waters to establish both maximum and normal chemical feed requirements under all known conditions of load, flow, and variation in demand.

Such tests should be run on fresh samples of effluent whenever feasible. In running a series of such tests, it is important to first determine the purpose of the test and then plan conditions so that only one factor is being studied at one time. Maximum color reduction with alum is generally achieved in the pH range from 5.6 to 6.5. This narrow range in these high colored waters occurs because impurities tend to stabilize the small floc particles which form earlier in the treatment and prevent them from growing larger. If prechlorination is used, good results are frequently obtained at pH values as high as 7.5. Chlorine partially destroys these colored substances, reducing the stabilizing action, and producing a lower residual color for a given coagulant dosage. When iron salts are used as a coagulant the floes tend to settle faster than with alum, but color removal is usually less. By adding chlo-

TABLE II.—Typical Results of Beaker Tests[1]

Sample No.	Lime (p.p.m.)	$CaCl_2$ (p.p.m.)	Alum (p.p.m.)	Treatment Results							
				P.P.M. as $CaCO_3$					Turbidity (p.p.m.)	Color (p.p.m.)	SiO_2 (p.p.m.)
				Ca^{++}	Mg^{++}	Total Hard.	Alk., Phenol.	Alk., MO			
Norm. Expect.	425	91	51	35	70	105	13	35	<10	<10	25
1	735	—	51	92	14	106	158	200	30	35	35
2	685	—	51	86	48	134	164	222	30	35	35
3	480	—	51	104	118	222	178	297	5	—	—
4	440	240	51	180	120	300	174	246	15	—	—
5	410	—	51	134	138	272	149	340	25	35	45
6	1,800	—	51	92	58	150	140	220	10	25	45
7	850	—	51	110	60	170	142	361	20	25	60

[1] Raw-water analysis: Ca^{++} 114 p.p.m., Mg^{++} 170 p.p.m., Na^{+} 337 p.p.m., total cations[2] 621 p.p.m.; HCO_3 386 p.p.m., SO_4 68 p.p.m., Cl 142 p.p.m., PO_4 25 p.p.m., total anions[2] 621 p.p.m.; SiO_2 75 p.p.m., turbidity 140 p.p.m., color 60 to 80 p.p.m., organic matter 800 to 900 p.p.m.
[2] Expressed as p.p.m. $CaCO_3$.

rine to the treatment, adequate color reduction can frequently be obtained. The order of addition of the alkali, coagulant, and coagulant aid is important and should be investigated as a part of these tests.

Table II shows some typical results of such beaker tests on a sample sewage plant effluent from a large southwestern city. In this series of tests, preparatory to recommendations for design of a large-scale clarification unit, not only were the conditions of maximum chemical feeding to be established but also the type of chemicals, the amount, and the order of addition of these chemicals.

The table shows results during the worst period encountered during an extensive series of tests. One unusual feature of this particular sewage plant effluent was the presence of abnormally high concentrations of silica. Color was reduced from more than 60 p.p.m. to less than 30 p.p.m., and turbidity to 30 p.p.m. Although the theoretical lime dosage for this water is about 30 grains per gallon, the actual dosage required was found to be 43. The addition of excess lime above this dosage resulted in an increased hydroxyl alkalinity and calcium hardness. These tests showed clearly that better clarification was obtained when activated silica was added before any of the other reagents. In the total test program more than 125 individual jar tests were performed.

To establish the effect of the presence of rather high concentrations of organic constituents in the sewage plant effluent, a sample was extracted with chloroform. The working theory was that some organic substances were stabilizing the calcium carbonate and magnesium carbonate precipitates and interfering in the proper reaction of the added lime, resulting in the excessive amounts of lime required for proper treatment. (Detergents such as alkyl aryl sulfates can be removed by extraction with chloroform). After chloroform extraction and separation of the chloroform mixture from the water, a conventional jar test was run on the remaining water sample. In this test the methyl orange alkalinity was reduced successfully. Using the theoretical lime dosage, the methyl orange alkalinity was reduced to 110 p.p.m. by 26 grains per gallon of lime and about 3 grains per gallon of alum.

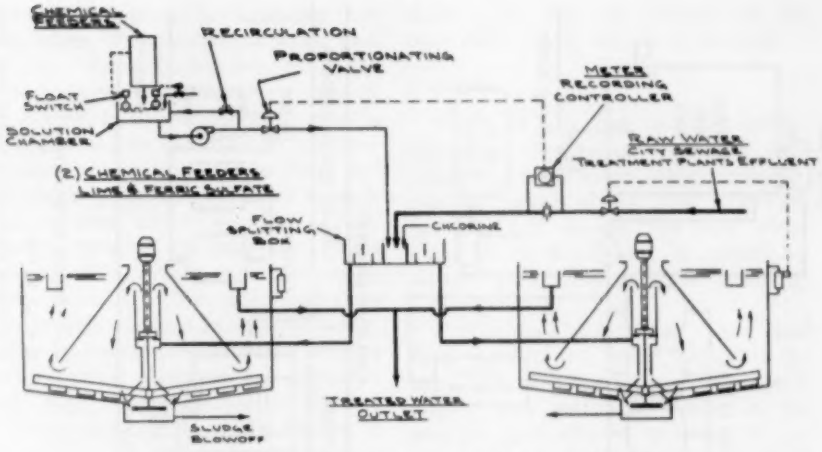


FIGURE 1.—Flow sheet of equipment at Plant A.

Design and Operation of Large-Scale Installations

Plant A

Based on laboratory and field tests, a large clarification plant was designed for a southwestern refinery to handle sewage plant effluent contracted for from a nearby city. Figure 1 is a flow sheet of this plant and a cross-section of the equipment involved. As is shown, two sludge contact units have been installed, each capable of handling a total flow of 750 g.p.m. with an approximate detention time of 2 hr.

Figure 1 also shows a flow diagram of the continuous automatic proportioning-type chemical feed system em-

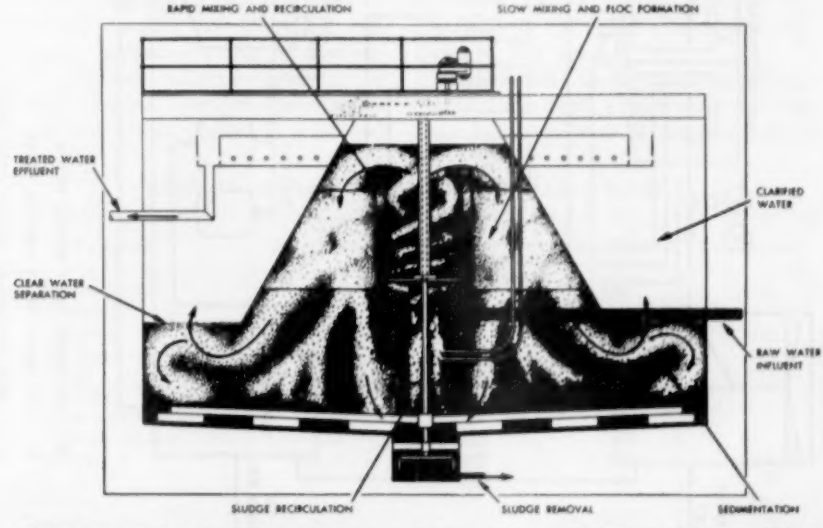
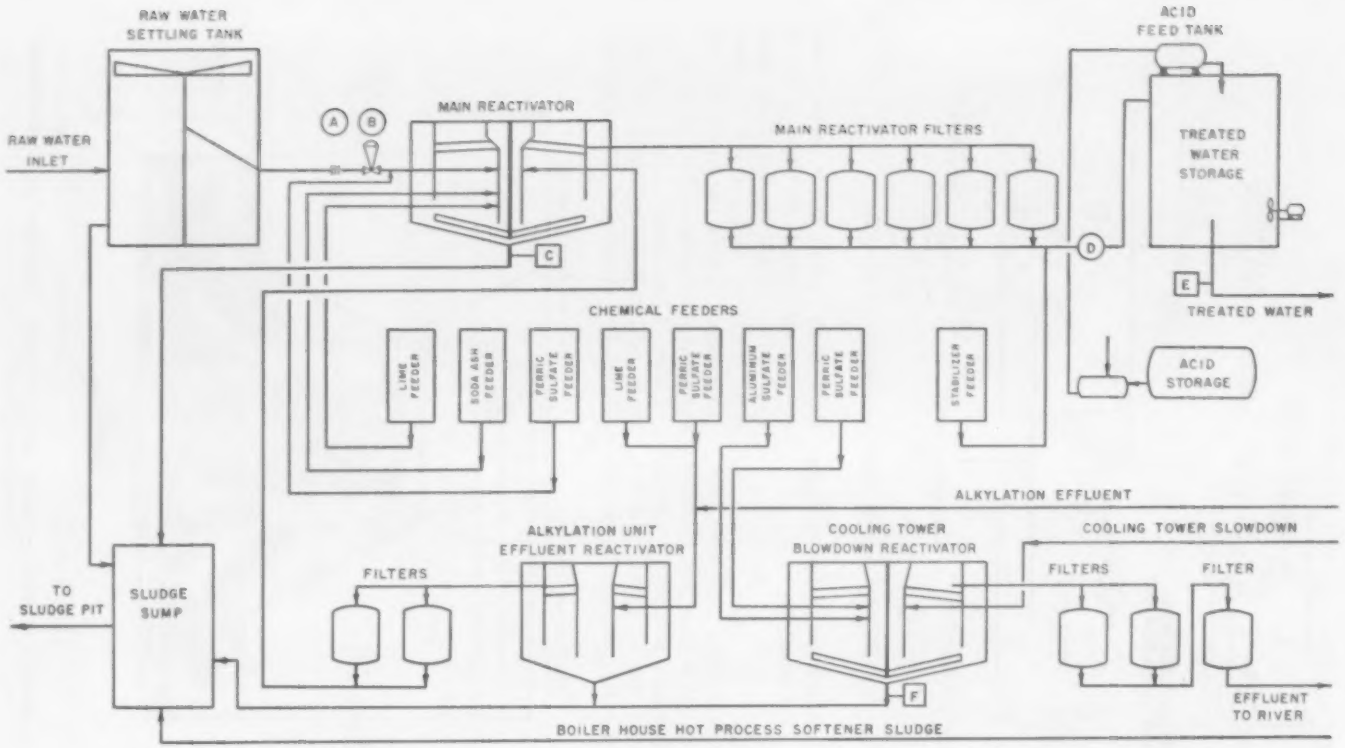


FIGURE 2.—Method of securing proper sludge contact. (Courtesy of Graver Water Conditioning Co.)



A — RAW WATER INLET ORIFICE METER
B — RAW WATER INLET CONTROL VALVE
C — TIMER CONTROLLED SLUDGE DRAW VALVE
D — TREATED WATER METER
E — pH METER
F — TIMER CONTROLLED SLUDGE DRAW VALVE

FIGURE 3.—Flow sheet for water treatment installation at Plant B, using municipal sewage treatment plant effluent as raw water.

ployed at this plant for handling iron salts, alum, lime, activated silica and chlorine. Provision has been made for feeding chemicals at various points in the system to obtain optimum results as established on the site. In addition to variations in rate of flow there are variations in concentrations of organic contaminants which require adjustment in chemical feeding rates. This chemical feed system provides maximum flexibility for adjustment to handle wide changes in composition.

The incoming sewage plant effluent and treatment chemicals are contacted with high concentrations of surface active sludge, as shown in Figure 2. These are mixed and recirculated within the inner flocculation and sludge contact section by means of a sludge impeller pump at about four or five times the incoming flow rate. In some cases it has been found practical to employ an airlift for recirculation of sludge in place of a mechanical recirculator. Such aeration is sometimes effective with high organic and bacteriological contamination. After flocculation, the treated water is passed upwardly through a shallow bed of suspended sludge, or, if found unnecessary, passed directly to the extensive effluent collector system. A separate sludge scraper mechanism collects the settled sludge in a central sludge pit from all sections of the conically shaped bottom of the unit.

Plant B

Figure 3 is a flow diagram of the treatment equipment facilities provided at a large southwestern refinery. During periods of low river flow, during the dry season, the raw water make-up to this plant is essentially sewage plant effluent from a nearby municipality.

Preliminary laboratory tests and field work at this plant indicated the need, not only for removal of organic matter and settleable solids in the sewage plant effluent, but also the removal of appreciable quantities of oil from refinery operation at concentrations up to 500 p.p.m.

Originally, 1,500 g.p.m. of oil-contaminated waste water was discharged into a small stream. As a result of the installation and operation of the equipment, about 300 g.p.m. is discharged as clarified waste water and 1,200 g.p.m. is re-used in the refinery after further treatment to soften the water and remove the oil. Table III gives analyses of typical waters going to and from the various items of equipment in this plant.

In operation, the high solids make-up water first enters a raw-water settling tank and then goes to the main chem-

TABLE III.—Analyses of Typical Waters, Plant B, in P.P.M.

Constituent	River Water	Raw Water from Settling Tank	Treated Water	Net Effluent
Dissolved solids	2,810	3,340	3,490	11,300
Hardness:				
Calcium	410	280	69	320
Magnesium	90	77	59	192
Total	500	357	128	512
Alkalinity:				
Phenolphthalein	0	68	85	—
Methyl orange	154	225	159	—
Chlorides	1,145	1,400	1,400	5,020
Oil	0	250	20	0
Sulfates	—	—	—	2,660
Ammonia ion	—	—	—	313
Cresols	—	—	—	0

ical sludge contact unit. Lime, soda ash, and ferric sulfate are added in optimum quantities and contact with large quantities of heavy surface active sludge provides the adsorptive action required to physically eliminate the suspended matter, oil, and other colloidal solids present in this water. Turbidities of less than 15 p.p.m. are reported, even during periods of high contamination. Concentrated oily sludge obtained from this process at the plant is burned to avoid lagooning.

Chemical operating costs average $0.04 to $0.05 per 1,000 gal. Savings obtained by re-use of clarified water at this plant amount to $10,000 to $15,000 per year. Furthermore, pollution of the small stream is eliminated by removing organic matter and oily waste prior to discharge.

The use of a sludge adsorption process for reducing organic matter, color, and other polluting materials has been found most effective whenever high concentrations of heavy, dense sludge can be maintained. This refinery is an excellent example of such an application of the sludge adsorption process.

Summary and Conclusions

Despite the severe shortage of water for industrial purposes in many parts of the country, possible use of sewage plant effluent for such purposes is frequently overlooked. The considerable number of plants which have successfully used such reclaimed water over a period of years should stimulate greater interest in this process. Subject to certain limitations discussed herein, modern treatment techniques make such use practical and economical.

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RESEARCH ON ACTIVATED SLUDGE

V. Rate of Biochemical Oxidation

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In the study of the activated sludge process it is necessary to differentiate between two modifications, as follows:

1. The original (conventional) process, with "complete" purification, in which the effluent satisfies the methylene blue test and the B.O.D. removal amounts to more than 90 per cent, often in the range of 93 to 97 per cent.
2. The so-called high-load or high-rate process, with partial purification and a B.O.D. removal of approximately 70 to 80 per cent. (In both cases purification of presettled sewage is assumed.)

It is certain that in more than one point there is a great difference between these two modifications. The difference becomes clear when two recent results are compared.

Wuhrmann's (1) pilot plant has an oxygenation capacity of approximately 25 to 30 g. per hr. per cu. m. With a load of 3,100 g. B.O.D. per 24 hr. per cu. m. (= 191 lb. per 1,000 cu. ft. per 24 hr.) he arrived at a B.O.D. removal of 82 to 83 per cent maximum.

Part IV of this series (2), reported on experiments in which a much higher oxygenation capacity was used (that is, approximately 360 g. per hr. per cu. m.), and a load of 4,200 g. B.O.D. per 24 hr. per cu. m. (= 260 lb. per 1,000 cu. ft. per day) was applied. The effluent satisfied the methylene blue test. The B.O.D. removal was 95 per cent.

These last experiments show that with high loads it is possible to obtain as good an effluent as in the normal process, provided the supply of oxygen is sufficient. It is of interest to note that in Wuhrmann's experiments the ratio of oxygenation capacity to B.O.D. load was approximately $\frac{24 \times 30}{3{,}100} = 0.23$. In the author's experiments with complete purification, this ratio was $\frac{24 \times 360}{4{,}200} = 2.06$. In sewage treatment plants of the conventional activated sludge type this ratio may be somewhere between 1.2 and 2.

From this it is clear that partial purification requires only a small part of the energy that has to be expended in the complete purification process. Hence, in those cases where complete purification is not needed, this method may be of great value.

The result that with high oxygenation capacities high loads can be completely purified (B.O.D. removal greater than 90 per cent) is of great importance for the practice of activated sludge treatment. In enlarging treatment plants and in building new ones this may represent a great saving in cost, because much less aeration tank volume is required.

To obtain more information it was necessary to make further investigations as to the relation between the rate of oxygenation and the rate of the purification process. These investigations may afford a clearer insight into the possibilities of practical application.

Description of Apparatus

Because investigation on a full-scale or even on a pilot-plant scale is almost impossible because of the very high

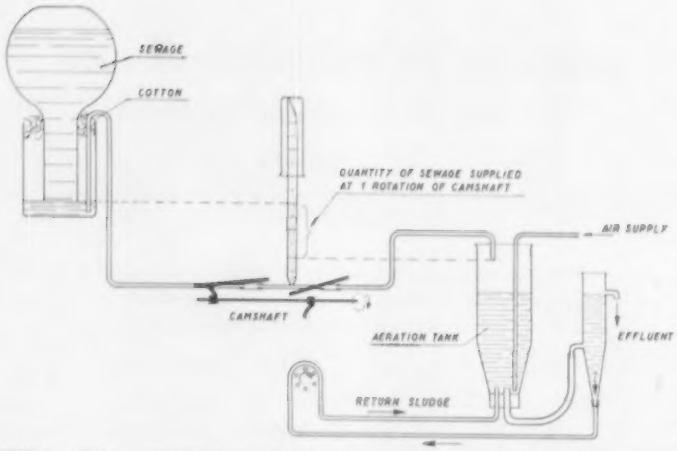

FIGURE 1.—Schematic diagram of laboratory unit for activated sludge experiments.

costs and because of several other difficulties, laboratory plants were used. These small laboratory plants worked so well, being in fact actual treatment plants in miniature, that it was possible to carry out the investigation and afterwards be perfectly convinced that the results will essentially hold good for practical activated sludge plants although, of course, caution and critical judgment are needed in transferring the results to practical conditions.

Each small treatment plant included an aeration bottle, a sedimentary settling tube, a small "tube-pump" for the return sludge, and an apparatus for dosing the sewage to be treated (see Figure 1). Some of the plants were subsequently provided with an instrument for the discontinuous removal of surplus sludge.

For the first apparatus (No. I), four 500-ml. bottles were used for the aeration tank. In most other apparatus only one 400-ml. aeration bottle was used. In this bottle the liquor is well mixed, so that conditions are identical in the whole of the aeration bottle. This is somewhat different from the conditions ruling in practice. Therefore, apparatus No. I was in use during the whole investigation, so that the results with the smaller plants could be compared with those of No. I.

Air was supplied by two-cylinder aquarium pumps driven by synchronous motors. At 100 r.p.m. each cylinder delivered approximately 600 ml. of air per minute. The rate of air supply was varied by connecting 1, 2, or 3 cylinders to the glass tube, which emerged in the liquor and had a 2.5-mm. aperture. The depth of water column was 14 cm. The oxygenation capacity was estimated for each air rate used.

The secondary settlement equipment consisted of glass tubes of the forms shown in Figure 1. For sewage flows up to 2.1 per day, tubes of 1.8-cm. diameter were used. At higher rates of sewage supply, tubes of 3.6-cm. diameter were used.

The sludge settling in the sedimentation tube was continually pumped back into the aeration bottle. By changing the tension of the rubber or plastic tube of the small "tube pump," the rate at which sludge was returned could be increased or decreased.

If the rate of increase in sludge content is not too high, it will suffice to remove the surplus sludge once in 24 hr. In some cases, at high rates

of growth, the sludge was removed automatically at short intervals.

The dosing apparatus for the sewage includes a calibrated tube with a ⊥-tube at its lower end. At each end of the ⊥-tube a rubber valve tube is connected. These rubber tubes are closed by a small clamp, these clamps being opened alternately by cams on a shaft. When the first clamp is opened the sterile sewage is siphoned from a constant level (see Figure 1) into the tube, the liquid ascending to a certain level in the tube. A short time after the first clamp is closed the second is opened, so that the liquid flows into the aeration bottle. The liquid in the tube then descends to a level corresponding to that of the end of the feeding tube. Therefore, at one rotation of the cam shaft a known quantity of liquid is fed to the aeration bottle.

The dosage rate can be varied in different ways, as follows:

1. By varying the difference in level.
2. By varying the diameter of the glass tube.
3. By varying the rotational speed of the cam shaft.

This dosing apparatus operates in a particularly successful manner. It can be used for any quantity of liquid to be fed, operating just as well for a supply of 50 ml. per 24 hr. as for 6 l. per 24 hr.; and just as well with sterilized synthetic sewage as with cotton-filtered sterilized domestic sewage. The tubes can be kept clean by being sterilized frequently (once in 2 or 3 days) with steam.

Further Data

The temperature throughout the experiments ranged from 19° to 21°C. with irregular deviations sometimes lasting a few hours. In some experiments the temperature was lowered, which fact is specially recorded in these cases.

The oxygenation capacity was determined as described elsewhere (3). The values given in the tables may be considered as average values of moderate accuracy.

In most of the experiments a sterilized synthetic sewage was used of a composition approximating that given by Butterfield (5). The concentration was 5/4 that of Butterfield, and in case of nitrification larger quantities of phosphate buffer were added in order to neutralize the nitric acid formed.

The following composition was used:

Peptone	375 mg.
Beef extract	250 mg.
Urea	62.5 mg.
NaCl	15 mg.
$CaCl_2$	7.5 mg.
$MgSO_4$	5 mg.
Distilled water	1,000 ml.

As buffer, 10 ml. or more per liter of medium was added of a mixture of 200 g. of K_2HPO_4 and 50 g. of KH_2PO_4 per liter.

The medium analysis was as follows:

Solids	610 mg./l.
Ash	80 mg./l.
N	110 mg./l.
B.O.D., 5-day	400 mg./l.
pH	7.2 – 7.3

In some experiments the same medium was used, but of higher concentration; in other experiments a cotton-filtered sterilized sewage of the city of The Hague was employed.

Experiments

In addition to apparatus No. I, six of the previously described laboratory treatment units with 400-ml. aeration tanks were used. The six units were exact duplicates, the only difference being in the oxygenation capacity. Different loads were applied according to the oxygenation capacity. A brief comprehensive survey of the various data gathered during the investigation is given in Table I, from which it can be ascertained that the degree of purification and the occurrence of

TABLE I.—Comprehensive Survey of Results of Purification Experiments at Various O.C./Load Values and Loads up to 6,000 g. B.O.D./24 hr./cu.m. (375 lb./24 hr./1,000 cu. ft.)

Lab. Unit	Oxygenation Capacity (g./hr.)[2]	B.O.D. Loading			Oxy. Cap. / Load	Mixed Liquor Susp. Solids (p.p.m.)	Mixed Liquor Oxygen Content (p.p.m.)	Nitrification[3]	Effluent		B.O.D. Removal (%)	Period to Which Results Relate (mo.)
		(g./24 hr.)[1]	(lb./24 hr.)[2]	Pop. Equiv.[1]					B.O.D. (p.p.m.)	Methylene Blue Test (hr.)		
I	90	800	50	23	2.7	3,400	—[4]	Complete	—[5]	>96[5]	100	16
		400	25	11.5	5.4	3,400–7,000	—[4]	Complete	—[5]	>96[5]	100	2
II	170	800	50	23	5.1	3,300	4.1	Complete	—[5]	>96[5]	100	14
		400	25	11.5	10.2	3,300–6,200	6.1	Complete	—[5]	>96[5]	100	2
III	300	800	50	23	9	2,900	5.1	Nearly Compl.	—[5]	>96[5]	100	12
		400	25	11.5	18	3,000–7,300	6.7	Complete	—[5]	>96[5]	100	2
		1,200	75	34.5	6	5,700	—	Complete	—[5]	>96[5]	100	¾
		1,600	100	46	4.5	6,500	3.7	Complete	—[5]	>96[5]	100	1½
IV	400	800	50	23	12	3,000	5.0	Nearly Compl.	—[5]	>96[5]	100	12
		400	25	11.5	24	2,800–5,600	7.1	Complete	—[5]	>96[5]	100	2
		1,200	75	34.5	8	4,400	—	Complete	—[5]	>96[5]	100	¾
		1,600	100	46	6	5,900	—	Nearly Compl.	—[5]	>96[5]	100	1
		2,400	150	69	4	6,200	2.7	Trace	—[5]	>96[5]	100	1
VII	170	2,000	125	57	2	2,000–4,400	4.2	Little	10	>96	97.5	7
	400	2,000	125	57	4.8	4,000	7.3	Some	—[5]	>96[5]	100	1
VIII	300	4,000	250	114	1.8	3,000–5,600	2.2	None	10	75	97.5	6
IX	400	6,000	375	171	1.6	4,000–6,200	0.6	None	20	60	95	6

[1] Per cubic meter.
[2] Per 1,000 cu. ft.
[3] Maximum attained.
[4] 1.5, 3, 4, 4.5 in tanks 1, 2, 3, 4.
[5] Not estimated.
[6] 2.3, 6.8, 6.8, 7.4 in tanks 1, 2, 3, 4.

nitrification in the plant depends primarily on the value of the relation

$$\frac{\text{Oxygenation capacity, in g./24 hr./cu.m.}}{\text{B.O.D. load, in g./24 hr./cu.m.}}$$

(abbreviated as O.C./load).

If this value is greater than 5, even in the one-bottle units, there is complete nitrification. Of course, there are some other conditions to be fulfilled. A high sludge content (more than 3,000 mg./l.) is favorable to complete nitrification. The pH value was regulated between 6.5 and 7 (6.8) by dosing the right quantity of phosphate buffer to the medium. It must also be borne in mind, when judging the results of the nitrification process, that the development of a nitrifying flora may take months, especially if conditions are not optimum.

Especially for the nitrification process, the conditions in apparatus I are somewhat more efficient than those in II because of the four aeration tanks. This is discussed later. For the moment, discussion is restricted to the following two principal results:

1. It has proved possible to purify and nitrify completely a load of approximately 50 population equivalents per cubic meter—that is, approximately 1,800 g. of B.O.D. per 24 hr. per cu.m. (112 lb. per 24 hr. per 1,000 cu. ft.) (nitrogen, 110 mg. per l.)—provided the rate of oxygen supply is sufficient (O.C./load value $= > 5$).

2. It has proved possible to purify a load of approximately 170 population equivalents per cubic meter—that is, approximately 6,000 g. of B.O.D. per 24 hr. per cu.m. (375 lb. per 24 hr. per 1,000 cu. ft.) with 95 per cent B.O.D. removal (no nitrification) at an O.C./load value of approximately 1.6.

This last result means that with these high loads the efficiency of the process is of the same order as in the conventional activated sludge process.

The question now arises: "To what limit can both oxygenation capacity

TABLE II.—Results with Laboratory Unit No. XI; Aeration Volume 20 Ml.; Synthetic Sewage with 400 P.P.M. B.O.D.

Period	Oxygenation Capacity (g./hr.)[1]	B.O.D. Loading			Oxy. Cap. / Load	Mixed Liq. Susp. Sol. (p.p.m.)	Effluent		B.O.D. Removal[2] (%)
		(g./24 hr.)[1]	(lb./24 hr.)[3]	Pop. Equiv.[1]			B.O.D. (p.p.m.)	Meth. Blue Test (hr.)	
Sept. 15–Oct. 2	2,000–2,400	40,000	2,500	1,143	1.4		55	—[4]	86
Oct. 3–Oct. 25	2,000–2,400	40,000	2,500	1,143	1.4		22	<24	94
Oct. 26–Nov. 6	3,600	60,000	3,750	1,700	1.4	Up to 12,000	100–36	3	75–91
Nov. 7–Nov. 22	3,600	60,000	3,750	1,700	1.4		29	<24	93
Nov. 23–Dec. 23	3,600	80,000	5,000	2,286	1.1		100	3	75[5]

[1] Per cubic meter.
[2] Per 1,000 cu. ft.
[3] Data include all poorer results due to stoppages and irregularities.
[4] Not estimated.
[5] Repeated breakdowns in air supply.

and load be increased, the O.C./load value remaining approximately 1.5 to 2, at the same time obtaining just as good results in the purification process as with lower loads?"

High Loading Experiments

From Table II it can be seen that with an O.C./load value of about 1.4 the load can be increased up to values of 60,000 g. B.O.D. per 24 hr. per cu.m., the B.O.D. removal remaining 93 per cent.

It must be said here that the values for oxygenation capacity given in Table II are not accurate. The determination of the oxygenation capacities in the small volumes (aeration tank volume only 20 ml.) can be fairly satisfactorily carried out by passing a flow of deoxygenized water through the aeration tank and determining the increase in oxygen content and the average detention time. However, the porous stones get clogged sooner or later, resulting in a decrease in air output of the pump and in oxygenation capacity. For the interpretation of the results, however, this is not so serious. Table II shows that up to very high oxygenation capacities the oxygen consumption by the activated sludge floc may be as intense as the oxygenation supply. The purification process can go on in the aeration tank at a rate which is 100 times that used in practice, the B.O.D. removal being more than 90 per cent and—an important consideration—with the same efficiency (O.C./load value approximately 1.4). From Table II it cannot be determined that, at a temperature of 20°C., the limit has been reached.

A further increase in oxygenation capacity, in the case of air supply, is hardly possible in these small volumes. Therefore, further research in this direction was postponed.

Temperature Experiments with Municipal Sewage

Before the former results can be transferred to the practice of activated sludge treatment, the following two questions must be answered:

1. Is municipal sewage purified at the same high rates of loading as the synthetic medium?

TABLE III.—Results with Laboratory Unit No. XIII; Aeration Volume 30 Ml.[1]; Cotton-Filtered Sterilized Municipal Sewage; Oxygenation Capacity/Load Value 2 to 4

Period	Temp. (°C.)	B.O.D. Loading			Sewage B.O.D. (p.p.m.)	Mixed Liquor Susp. Sol. (p.p.m.)	Effluent		B.O.D. Removal[4] (%)
		(g./24 hr.)[2]	(lb./24 hr.)[3]	Pop. Equiv.[3]			B.O.D. (p.p.m.)	Meth. Blue Test (hr.)	
Nov. 12–Nov. 17	19–21	18,740	1,184	535	225		111–20	10–30	70–90
Nov. 18–Dec. 1	19–21	23,707	1,482	677	221		9	>78	96
Dec. 2–Dec. 5	10–11	26,810	1,676	766	221		18	40	92
Dec. 6–Dec. 9	6–8	43,365	2,713	1,239	350		121	5	65
Dec. 10–Dec. 19	8–5	23,800	1,488	680	350		49	<20	86
Dec. 20–Dec. 21	3	12,880	805	368	155		33	—[5]	79
Dec. 22–Jan. 1	6–7	13,300	831	380	155		30	—[5]	81
Jan. 1–Jan. 8	6–8	26,670	1,667	762	220		41	<20	81
Jan. 9–Jan. 21	9–11	22,715	1,420	649	275		17	63	94
Jan. 22–Feb. 3	3–5	21,175	1,323	605	275		38	<24	86
Feb. 4–Feb. 16	4–5	10,675	667	305	86		13	96	85

4,000–10,000

[1] Oxygenation capacity 2,000 g. per hr. per cu.m.
[2] Per cubic meter.
[3] Per 1,000 cu. ft.
[4] Data include all poorer results due to stoppages and irregularities.
[5] Not estimated.

2. What is the influence of temperature?

Table III gives the results of experiments in which cotton-filtered sterilized domestic sewage was treated. A load of 25,000 g. B.O.D. per 24 hr. per cu.m. is purified nearly as well at approximately 10°C. as at 20°C. At temperatures below 10°C. the result is somewhat lower, but is still remarkable. At a load of 25,000 g. B.O.D. the O.C./load value may have been in the neighborhood of 2.

Discussion

Biochemical Oxidation a Rapid Process

The results (Table III) indicate that the rate of biochemical oxidation in activated sludge treatment can be increased up to at least 50 times the rate at which the process goes on in a normally loaded activated sludge tank in practice. Probably, as in the experiments with synthetic medium, under the right conditions the biochemical oxidation of sewage can be increased 100-fold or more.

At these high rates the efficiency of the process as expressed in the O.C./load value is the same as in present practice. This result, of course, is extremely interesting. A previous section (4) contained a theoretical discussion on the distribution of oxygen in the activated sludge floc. The value α was used, being the amount of oxygen, in grams, which becomes bound per second in 1 ml. of floc volume when the oxygen concentration is 1 g. per ml. From data in practice, a value of approximately 0.1 was deduced for α. From the foregoing it is clear that this value may be much higher and may be calculated as approximately 2 to 5 g. per sec. In the former publication a table was computed giving the distribution of oxygen in the floc and the comparative rates of biochemical oxidation for varying sizes of floc and varying states of turbulence when $\alpha = 0.1$. Table IV gives the same calculation for $\alpha = 5$. From this table it is seen that the importance of turbulence and small size of floc is far higher than in the case $\alpha = 0.1$. The oxygen cannot penetrate in any floc farther than to a depth of about 25 to 29 μ. Only in the smallest flocs, and only in the case of strong turbulence, is almost the whole of the floc active in the process of biochemical oxidation. In the larger flocs (2,000 μ.) and with slight turbulence not more than 0.1 per cent of the floc volume is active.

Temperature Not a Ruling Factor

One of the most puzzling questions in the study of activated sludge treatment as carried out in practice is the one as to what may be the reason(s) that the process goes on almost as well at a temperature of 3° to 5° C. as it does at 20° C. This fact is in disagreement with the relation observed in living nature anywhere, that with an increase of temperature over a range of 10° C. (in the correct region) the rate of the process increases to 2 or 3 fold. After the foregoing, the answer may now be obvious. In practice the rate of activated sludge process is not regulated by temperature, but by the oxygen supply. In other words, the oxygen supply is always the ruling "minimum factor."

From Table III it might be gathered that at high loads there is an influence of temperature and that below 10° C. the limit of the rate of biochemical oxidation is reached. Probably it is of interest to investigate whether there is a difference in this respect between the partial and the complete purification process.

Theoretical O.C./Load Values

From a theoretical point of view it is clear that as long as the rate of biochemical oxidation does not act as a brake, the efficiency of the process is independent of the rate of oxygen supply as long as the O.C./load value is

TABLE IV.—Distribution of Oxygen in Floc and Comparative Rates of Biochemical Oxidation, for Varying Sizes of Floc and Conditions of Turbulence when $\alpha = 5.0$ [1]

Floc Size, r (μ)	Independent of Turbulence, n			$n = 100$[2]			$n = 10$			$n = 1$			$n = 1/4$			$n = 1/10$			$n = 1/100$[3]		
	Oxygen Penetration Depth (μ)	Volume, Conc. $O_2 > 0$ (%)	Average O_2 Conc.[4] (% c_p)	c_p (% c_v)	c_m (% c_v)	Rate of Oxygen Fixation[5]	c_p (% c_v)	c_m (% c_v)	Rate of Oxygen Fixation[5]	c_p (% c_v)	c_m (% c_v)	Rate of Oxygen Fixation[5]	c_p (% c_v)	c_m (% c_v)	Rate of Oxygen Fixation[5]	c_p (% c_v)	c_m (% c_v)	Rate of Oxygen Fixation[5]	c_p (% c_v)	c_m (% c_v)	Rate of Oxygen Fixation[5]
10	10	100	97.8	96.4	85.9	94.3	89.4	79.7	87.4	72.8	64.9	71.2	57.3	51.1	56.0	45.9	40.9	44.9	21.1	18.8	20.6
50	29	92.6	67.6	89.4	0	56.0	72.8	0	45.6	45.9	0	28.7	29.8	0	18.7	21.1	0	13.2	7.8	0	4.9
100	26	59.5	57.3	88.3	0	30.1	70.6	0	24.1	43.1	0	14.7	27.5	0	9.4	19.3	0	6.6	7.0	0	2.4
200	25.5	33.6	53.4	88.1	0	15.8	70.1	0	12.6	42.6	0	7.6	27.1	0	4.9	19.0	0	3.4	6.9	0	1.2
500	24	13.7	51.3	87.5	0	6.2	68.9	0	4.8	41.2	0	2.9	25.9	0	1.8	18.1	0	1.3	6.5	0	0.5
2,000	24	3.6	49.2	87.5	0	1.6	68.9	0	1.2	41.2	0	0.7	25.9	0	0.5	18.1	0	0.3	6.5	0	0.1

[1] Legend:

c = oxygen concentration;
c_m = at center of floc;
c_p = in water/floc interfacial surface;
c_v = in liquid mass containing floc.

[2] Strong turbulence.

[3] Very slight turbulence.

[4] In volume where oxygen concentration greater than 0.

[5] Comparative.

kept constant. These O.C./load values can be computed for the complete purification process with and without nitrification.

For a load of 1,000 g. B.O.D., at 20° C., the total oxygen demand (20-day demand) may be approximately 1,460. In the purification process a part is oxidized (80 per cent?) and another part of the matter is assimilated (20 per cent?). From the 80 per cent to be oxidized (1,168 g.) a part escapes with the effluent. In the case of 92 per cent removal, for instance, this comes to 117 g. Therefore, about $1,168 - 117 = 1,050$ g. of oxygen have to be supplied.

Approximately, for 1,000 g. B.O.D. to be removed, about 1,000 g. of oxygen will have to be supplied. If the oxygen content in the aeration tank has a mean value of 3 p.p.m., the oxygenation capacity must be $\frac{9.1}{9.1-3} \times 1,000 =$ 1,500 g. per hr. per cu.m. Hence the O.C./load value must be approximately 1.5.

In the case of complete nitrification (110 mg. N per l.—400 mg. B.O.D. per l.), above the 1,000 g. B.O.D. there is an oxygen demand for the oxidation of the nitrogen of approximately $\frac{1,000}{400} \times 110 \times 4 \times \frac{16}{14}$ $= 1,250$ g. Therefore, approximately 2,250 g. of oxygen have to be supplied. If an oxygen content of 5 p.p.m. is assumed in the aeration tank, the oxygenation capacity must be approximately $\frac{9.1}{9.1-5} \times 2,250 = 5,000$ g. per hr. per cu.m.

The O.C./load value, therefore, is about 5.

It can now be seen more clearly why, in the case of laboratory plant No. I, there is complete nitrification at a lower O.C./load value. This is due to the fact that in laboratory plant No. I the oxygen content is lower in the first aeration bottles. In these first bottles the oxygen supply is more efficient (larger deficit).

In the case of partial purification at low O.C./load values, only a small part of the organic matter is oxidized. For instance, from Wuhrmann's experiments (O.C./load value 0.23, B.O.D. removal 82 per cent) the following can be calculated:

For 1,000 g. B.O.D. there may be a total oxygen demand of approximately 1,460 g. In the effluent there escapes 180 g. 5-day B.O.D. (that is, 260 g. 20-day B.O.D.) Thus, in the process a total 20-day B.O.D. of approximately 1,200 g. is removed. If it is assumed that in the case of partial purification the oxygen content in the aeration tank is approximately nil, then about 230 g. of oxygen are supplied.

From this it may be concluded that with the surplus sludge $1,200 - 230$ g. $= 970$ g. of 20-day B.O.D. (that is, approximately 650 g. of 5-day B.O.D.) are removed in a non-oxidized condition (that is, as bacterial body, "reserve food" in bacteria, and as organic matter adsorbed on the floc).

Advantages

For the practice of activated sludge purification the principal result of the foregoing experiments is that it has been shown that the rate of biochemical oxidation itself is very high.

Therefore, increasing both the oxygenation capacity and the load by 10- or 20-fold does not put the process at the border-line of what is just possible. Even then there is still quite some distance to the limit of what is possible. Moreover, the efficiency of the process at these high loadings is the same.

In a former publication (3) the results of experiments in a brush aeration plant with a 6- or 8-fold load were given. A subsequent section, after a theoretical study of the solution of oxygen from an air bubble, will discuss in what way the principle of in-

tense aeration might be used in air diffusion plants.

Conclusions

1. In study of the activated sludge process it is necessary to differentiate between two modifications: (a) the original process with complete treatment (B.O.D. removal > 90 per cent); and (b) the so-called high-load process, with partial treatment (B.O.D. removal 70 to 80 per cent).

2. The ratio

$$\frac{\text{oxygenation capacity (g. } O_2 \text{ per hr. per cu.m.)}}{\text{load (g. 5-day B.O.D. per hr. per cu.m.)}},$$

abbreviated to O.C./load value, determines the course of the purification process.

3. It has proved possible to treat and nitrify completely a load of approximately 1,800 g. 5-day B.O.D. per 24 hr. per cu.m. = 112 lb. per 24 hr. per 1,000 cu. ft. (nitrogen 110 mg. per l.), provided the rate of oxygen supply is sufficient (O.C./load value approximately 5).

4. It has proved possible to treat completely loads up to 60,000 g. 5-day B.O.D. per 24 hr. per cu.m. (3,750 lb. per 24 hr. per 1,000 cu. ft.) with a B.O.D. removal of approximately 93 per cent, the O.C./load value being approximately 1.4 (synthetic sewage, 5-day B.O.D. 400 p.p.m., temperature 20° C.)

5. A load of 25,000 g. 5-day B.O.D. (1,560 lb. per 24 hr. per 1,000 cu. ft.) municipal sewage was nearly as satisfactorily purified at 10° C. as at 20° C. (B.O.D. removal 92 to 94 per cent and 96 per cent, respectively).

6. In the practice of the activated sludge process, the rate of the process is not regulated by temperature but by the oxygen supply. In other words, the oxygen supply is always the ruling "minimum factor."

7. If both the oxygenation capacity and the load are increased to 10 or 20 times, the process is still far from the limit of what is possible.

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STUDIES OF BIOCHEMICAL OXIDATION BY DIRECT METHODS

V. Effect of Various Seed Materials on Rates of Oxidation of Industrial Wastes and Organic Compounds *

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In recent years there has been a growth of interest in the problem of seeding of the dilution water in the B.O.D. test. Efforts have been made to produce a standard seed material (1), as well as a standard sewage of statistically known B.O.D. against which to measure the activity of sewage seed. The development of a direct method for measuring biochemical oxidation of wastes and organic compounds has allowed a new approach to the problem of comparative evaluation of seed materials (2)(3). Use of this method may help to answer the following questions:

1. Do the oxidation results obtained for wastes and organic compounds with normal sewage seeding give any indication of the relative treatability of these wastes when using aerobic biological methods?

2. Is normal sewage seeding the most desirable method for determining oxygen demand of both raw and treated wastes from the standpoint of (a) time required for and the information derived from the determination, and (b) evaluation of treatment plant load and process control?

3. What is the relative effectiveness of various seed materials for measurement of oxygen demand of wastes?

4. Can oxidation rate measurements with various seed materials be used to predict the relative effectiveness of various aerobic treatment methods?

This paper presents the results of a comparative study of the effect of a number of seed materials on the oxidation of industrial wastes and organic compounds. The results obtained are discussed with the foregoing problems in mind.

Experimental Procedure

Materials Used

The industrial wastes used included rag, jute, sulfite pulp cooking liquors from several paper mills, spent yeast nutrient waste, and chewing gum washing waste. The organic compounds studied included methanol, ethanol, isopropanol, butanol, and an equal concentration mixture of the four alcohols. All wastes were neutralized, and nitrogen and phosphorus were added to all of the substances studied to maintain a B.O.D.:N:P ratio of 60:3:1. The wastes were studied at concentrations providing an initial B.O.D. load of 1,500 p.p.m. in the test sample. The alcohols were studied at a concentration of 1,000 p.p.m. as alcohol in the test samples.

Sewage for seed purposes was obtained from a municipal sewage treatment plant and was cotton filtered prior to its use. Activated sludge was obtained from an institutional sewage treatment plant.

Measurement of Oxidation and Purification Rates

In general, test samples of 200 ml. were prepared, and an aliquot portion was placed in the Warburg apparatus

* Paper of the Journal Series, New Jersey Agricultural Experiment Station.

for oxidation rate measurement. The remainder of the test sample was aerated by agitation on a shaker shelf. All work was done at 20° C. The method employed for differentiating oxidation and purification rates was that described previously (4). Purification rate data were obtained by periodic removal of settled supernatant from the shaker shelf aerated test sample for B.O.D. analysis to determine the amount of B.O.D. removal during the particular time interval.

Methods of Seeding

In all cases, normal sewage seeding was accomplished with 10 per cent by volume of sewage in the test sample. Acclimatized dispersed growth aeration seed was prepared for the industrial wastes by drawing effluent from sewage seeded samples after three days aeration and reseeding new waste samples with this material with 25 per cent seed volume. This procedure was then repeated daily for 10 transfers. Acclimatized dispersed growth aeration seed was prepared for the alcohols by drawing effluent from sewage seeded samples of 1,000 p.p.m. ethanol, butanol, and mixed alcohols after four to six days aeration, and reseeding new samples with this material, using 20 per cent seed volume. Daily transfers were made for 10 days, after which both settled and unsettled dispersed growth aeration seed was used for oxidation rate studies. Normal activated sludge seeding was accomplished with 2,000 p.p.m. sludge solids concentration. Acclimatized aerobic sludge for the industrial wastes was prepared by making five successive daily transfers for each waste, starting with 2,000 p.p.m. normal activated sludge. Oxidation and purification rates were then measured with 2,000 p.p.m. sludge solids. Acclimatized activated sludge for the alcohols was prepared by making eight successive daily transfers. Oxidation and purification rates were then measured as described.

Rates of Sludge Accumulation

Sludge accumulation rates were measured during activated sludge treatment of the alcohols to obtain data for comparison with that previously obtained for industrial wastes. The method used was that described previously.

Experimental Results for Five Industrial Wastes

Normal Sewage Seeding

Rag, jute and yeast wastes gave similar results, with sulfite waste showing a slight initial oxidation lag. Gum waste gave a lag period of two days, following which there was a rapid increase in oxidation so that 1,150 p.p.m. oxygen demand was exerted on the third day as against 195 p.p.m. on the first day. Rag, jute, yeast and sulfite wastes all gave K_{oxid} values of about 0.1 (Table I).

Dispersed Growth Aeration Seeding

A general increase in oxidation rates resulted with use of dispersed growth seed (Table II). K_{oxid} values varied from 0.35 to 0.55, representing a four-

TABLE I.—Rates of Oxidation of Five Industrial Wastes at 1,500-P.P.M. B.O.D. Concentration with 10 Per Cent Sewage Seed

Time (days)	Rag	Sulfite	Jute	Yeast	Gum
	Cumulative Oxygen Utilization (p.p.m.)				
1	450	230	500	480	195
1.5	690	520	650	850	320
2	900	810	900	1,110	475
3	1,210	1,160	1,180	1,410	1,150
4	1,420	1,385	1,365	1,600	1,480
5	1,540	1,500	1,570	1,740	1,760
	K_{oxid}				
	0.1	0.1	0.1	0.1	2-day lag

TABLE II.—Rates of Oxidation of Five Industrial Wastes at 1,500-P.P.M. B.O.D. Concentration with 25 Per Cent Dispersed Growth Seed

Time (hr.)	Rag	Sulfite	Jute	Yeast	Gum
CUMULATIVE OXYGEN UTILIZATION (P.P.M.)					
3	125	135	70	90	90
6	265	420	165	240	190
12	540	770	730	540	590
24	950	995	920	1,085	1,190
K_{oxid}					
	0.4	0.55	0.45	0.35	0.4
B.O.D. REMOVAL (%)					
12	52	42	68	39	35
24	68	64	77	71	63

fold increase in rate constants compared with sewage seeding. Average K_{oxid} was 0.4. The highest oxidation rates were obtained for sulfite waste, while the highest purification on B.O.D. removal was obtained with jute waste. Average B.O.D. removals at 12- and 24-hr. aeration were 47 and 69 per cent, respectively.

Normal Activated Sludge Seed

Using normal activated sludge, the oxidation rate constants ranged from 0.15 for gum waste to 0.35 for jute and yeast wastes (Table III). The rate constants were from 2 to 3.5 times higher than those obtained with normal sewage seed, but lower than those for dispersed growth aeration. Twelve- and 24-hr. B.O.D. removals averaged 43 and 64 per cent, respectively.

Acclimatized Activated Sludge Seed

In all cases the K_{oxid} values were higher than those for all other seed materials (Table IV). The values varied from 0.55 for gum waste to 1.3 for sulfite waste, averaging 0.85 as against 0.27 with normal activated sludge. The 12-hr. B.O.D. removal varied from 82 to 90 per cent, averaging 86 per cent. The 24-hr. B.O.D. removal varied from 86 to 99 per cent, averaging 94 per cent.

TABLE III.—Rates of Oxidation of Five Industrial Wastes at 1,500-P.P.M. B.O.D. Concentration with 2,000 P.P.M. Normal Activated Sludge Seed

Time (hr.)	Rag	Sulfite	Jute	Yeast	Gum
CUMULATIVE OXYGEN UTILIZATION (P.P.M.)					
3	55	105	115	140	55
6	125	180	220	235	95
12	355	345	550	510	170
24	660	610	760	1,225	310
48	1,180	905	1,170	—	1,175
K_{oxid}					
	0.2	0.3	0.35	0.35	0.15
B.O.D. REMOVAL (%)					
12	31	47	65	47	23
24	53	71	72	95	28

TABLE IV.—Rates of Oxidation of Five Industrial Wastes at 1,500-P.P.M. B.O.D. Concentration with 2,000 P.P.M. Acclimatized Activated Sludge Seed

Time (hr.)	Rag	Sulfite	Jute	Yeast	Gum
CUMULATIVE OXYGEN UTILIZATION (P.P.M.)					
2	335	210	250	200	95
4	630	440	370	365	225
6	750	630	480	555	380
12	1,005	830	720	1,070	850
24	1,260	945	1,035	1,410	1,195
K_{oxid}					
	1.1	1.3	0.6	0.7	0.55
B.O.D. REMOVAL (%)					
12	86	83	82	96	84
24	86	93	99	98	94

Experimental Results for Several Alcohols

Normal Sewage Seed

Lag periods before onset of active oxidation were noted for all the alcohols used when normal sewage seed was used (Table V). A lag of at least 5 days was obtained for isopropanol, 3 days for methanol, and only 1 day for ethanol, n-butanol, and an equal concentration mixture of all four alcohols. The difficulty encountered in oxidizing 1,000 p.p.m. concentrations of methanol and isopropanol individually was hardly evident in the mixture of all four alcohols for which the oxidation data were similar to that for ethanol and n-butanol.

Dispersed Growth Aeration Seed

After acclimatization by the dispersed growth aeration process, there was a sharp increase in the rate of oxidation of all alcohol samples when using either settled or non-settled seed (Table VI). While the 3-day oxygen demand with sewage seeding of methanol was 45 p.p.m., it was increased to 740 p.p.m. in 24 hr. and 920 p.p.m. in 12 hr. when using settled and non-settled seed, respectively. The 1-day lag periods observed for ethanol, n-butanol and the mixed alcohols were completely eliminated. Even with acclimatized seed, isopropanol continued to yield poor results, although the oxidation lag period was cut to less than one day. Use of non-settled seed produced more rapid oxidation of the alcohols than did settled seed. As an example, n-butanol settled seed produced 205 p.p.m. oxygen demand in 12 hr. while non-settled seed produced 515 p.p.m. oxygen demand in the same time. A more striking improvement was noted for methanol, where settled seed produced 50 p.p.m. oxygen demand in 6 hr., compared with 860 p.p.m. for non-settled seed in the same time.

TABLE V.—Rates of Oxidation of Alcohols at 1,000-P.P.M. Concentration with 10 Per Cent Sewage Seed

Time (days)	Methanol	Ethanol	Isopropanol	n-Butanol	250 P.P.M. Each
Cumulative Oxygen Utilization (p.p.m.)					
1	35	95	35	45	95
2	35	1,230	35	1,150	750
3	45	1,360	40	1,650	810
4	270	1,470	55	1,750	890
5	600	1,500	75	1,790	1,110
5-Day Dilution B.O.D. (p.p.m.)					
	900	1,260	1,290	1,500	1,240

TABLE VI.—Rates of Oxidation of Alcohols at 1,000-P.P.M. Concentration with 20 Per Cent Settled and Non-Settled Dispersed Growth Aeration Seed

Time (hr.)	Methanol	Ethanol	Isopropanol	n-Butanol	250 P.P.M. Each
Cumulative Oxygen Demand, Settled Seed (p.p.m.)					
2	15	45	25	25	20
4	25	100	45	45	40
6	50	145	55	75	75
12	155	524	95	205	200
24	740	1,220	200	730	700
48	805	1,500	450	1,540	1,000
5-Day Dilution B.O.D. (p.p.m.)					
	930	1,250	1,590	1,650	1,350
Cumulative Oxygen Demand, Non-Settled Seed (p.p.m.)					
2	225	115	40	55	85
4	605	270	75	115	150
6	860	350	100	175	235
12	920	895	180	515	560
24	1,025	1,390	440	1,330	965
48	1,190	1,635	975	1,880	1,170
5-Day Dilution B.O.D. (p.p.m.)					
	1,070	1,540	1,800	1,880	1,500

Normal Activated Sludge Seed

Using normal activated sludge, isopropanol was the most difficultly oxi-

TABLE VII.—Rates of Oxidation of Alcohols at 1,000-P.P.M. Concentration with 2,000 P.P.M. Normal Activated Sludge Seed

Time (hr.)	Methanol	Ethanol	Isopropanol	n-Butanol	250 P.P.M. Each
Cumulative Oxygen Demand (p.p.m.)					
6	20	165	65	130	120
12	70	555	150	375	370
24	190	940	240	1,030	640
48	435	1,010	380	1,280	1,095
72	820	1,025	670	1,335	1,115
B.O.D. Removal (%)					
12	12	85	18	52	35
24	33	90	50	91	68
48	93	94	94	92	93

dized alcohol in the group when normal sewage seed was used. (Table VII). Aeration for 24 hr. resulted in only 240 p.p.m. oxygen demand, as compared with a 5-day dilution B.O.D. of 1,290 p.p.m. Aeration for 48 hr. was necessary to accomplish 93 per cent B.O.D. reduction. Poor results were also obtained with methanol; namely, a 24-hr. oxygen demand of 190 p.p.m. as compared with a 5-day dilution B.O.D. of 900 p.p.m.

Oxidation and purification rates obtained with ethanol and methanol were significantly higher than for the other alcohols. Thus, with ethanol a 12-hr. aeration resulted in 85 per cent B.O.D. reduction. With n-butanol, a reduction of 91 per cent was obtained in 24 hr. Aeration of a mixture of the four alcohols with normal activated sludge produced results intermediate to those for methanol-isopropanol and ethanol-butanol.

Acclimatized Activated Sludge Seed

Acclimatization produced sharp increases in rates of oxidation and purification of the alcohols as in the case of the industrial wastes previously reported, particularly for the alcohols that had shown poor oxidation rate constants. The oxidation rate constants ranged from 0.9 for isopropanol to 1.4 for ethanol, and purification rate constants ranged from 1.4 to 4.0 for the same compounds (Table VIII). These rate constants compare well with those reported earlier for various industrial wastes.

As an example of the improvement in oxidation and purification, the data for isopropanol are cited. After acclimatization, a 12-hr. oxygen demand of 1,235 p.p.m. was obtained, compared with only 150 p.p.m. with normal sludge. B.O.D. removal in 12 hr. was increased from 18 per cent to 97 per cent after acclimatization.

Rate of Sludge Accumulation During Alcohol Oxidation

As an adjunct to the foregoing study, measurements of sludge accumulation rates were made during oxidation of 1,000-p.p.m. alcohol concentrations, using acclimatized activated

Table VIII.—Rates of Oxidation of Alcohols at 1,000-P.P.M. Concentration with 2,000 P.P.M. Acclimatized Activated Sludge Seed

Time (hr.)	Methanol	Ethanol	Isopropanol	n-Butanol	250 P.P.M. Each
Cumulative Oxygen Demand (p.p.m.)					
2	175	270	270	220	330
4	380	475	420	465	570
6	580	670	580	750	650
12	960	865	1,235	1,065	970
24	985	990	1,390	1,235	1,175
K_{oxid}					
	1.3	1.4	0.9	1.0	1.2
B.O.D. Removal (%)					
4	57	82	38	65	70
6	85	95	58	98	86
12	93	95	97	98	93
K_{pur}					
	2.5	4.0	1.4	2.5	3.5

TABLE IX.—Relation Between B.O.D. Loading and Volatile Sludge Solids Accumulated During Alcohol Oxidation

Sample	Vol. Solids Accumulated (p.p.m.)	B.O.D. Load Applied (p.p.m.)	Sol. Accum. / B.O.D. Load
Methanol	145	900	0.16
Ethanol	390	1,260	0.31
Isopropanol	115	1,290	0.09
n-Butanol	425	1,500	0.28
Average	255	1,240	0.21
250 p.p.m. each	255	1,240	0.21

sludge. The results are given in Table IX.

Accumulation rates for methanol and isopropanol were both lower than for ethanol and n-butanol. The average rate for the group was equal to that obtained with a mixture containing 250 p.p.m. of each of the four alcohols. The rate was significantly lower than that previously observed for a group of industrial wastes.

Discussion of Results

Comparison of Seed Effectiveness

A graphic comparison of oxidation rates obtained for one waste and the mixed alcohols is shown in Figure 1. The comparison of results obtained with the industrial wastes and organic compounds using several types of seed material reveals that the order of seed effectiveness is as follows. The most effective seed is acclimatized activated sludge, followed by non-settled dispersed growth seed, settled dispersed growth seed, normal activated sludge, and finally normal sewage seed. Two factors are involved in this ranking; namely, quantity of seed material and seed acclimatization. Thus, with non-acclimatized seed, normal activated sludge produces higher oxidation rates than normal sewage because of the higher seed concentration; with acclimatized seed, activated sludge is superior to mixed dispersed growth seed, which is more effective than settled dispersed growth seed. In comparing dispersed growth seed with normal sewage, both factors are involved, since during repeated exposure of the seed to the particular waste, not only is there a buildup of seed concentration, but the buildup is probably a result of increase in numbers of those organisms specifically responsible for the oxidation of the waste.

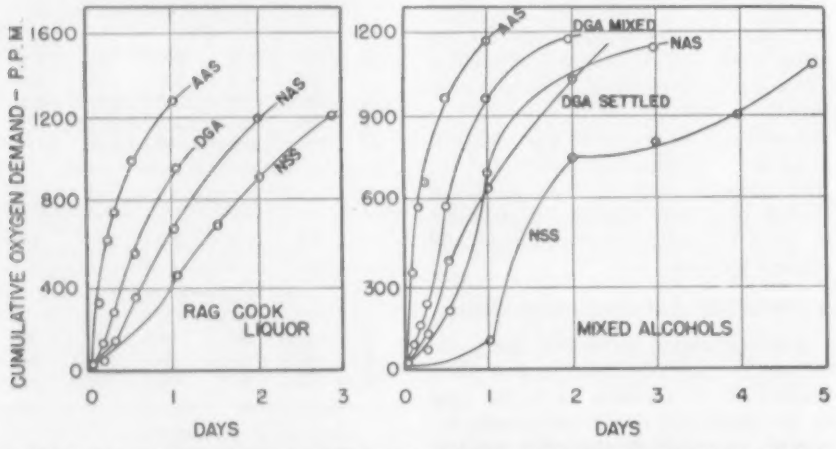

FIGURE 1.—Comparison of oxidation rates for rag cook liquor and mixed alcohols, using various seed materials. NSS—Normal sewage seed; NAS—Normal activated sludge; AAS—Acclimatized activated sludge; DGA—Dispersed growth aeration.

Differences in Oxidizability of Several Industrial Wastes

While the results obtained for each waste follow the same pattern of seed effectiveness previously given, there were significant differences between wastes using a given type of seed. Such differences must be explained by differences in chemical composition of the waste materials. Thus, the most difficultly oxidized waste, using any type of seed, was chewing gum washing waste. The conditions of gum washing are not particularly drastic, so there is little occasion for chemical breakdown of the stable impurities present in the gum. Highest oxidation rates generally were obtained with waste sulfite liquor, which is rich in 5- and 6-carbon sugars, which may be readily metabolized. Detailed chemical analysis of the wastes, coupled with available information concerning microbial metabolism, would probably fill in this picture of relationship between chemical composition and ease of microbial oxidation.

Differences in Oxidizability of Several Alcohols

It is of interest that the 1- and 3-carbon alcohols were less readily oxidized than the 2- and 4-carbon alcohols, using the various types of seed material. It would be worthwhile to extend this study further into the series of alcohols and into other groups of homologues, such as the aldehydes and organic acids. Again, the explanation must lie in differences of chemical structure, correlated with the frequency of occurrence of the specific organisms capable of oxidizing these substrates. It was observed that the rate of sludge accumulation was greater for the 2- and 4-carbon alcohols than the 1- and 3-carbon alcohols. This suggests that the higher oxidation rates result in faster rates of cell synthesis, since more energy is being made available for this purpose.

Differences in Sludge Accumulation Rates

As a group, oxidation of the alcohols produced lower rates of sludge accumulation than did oxidation of the industrial wastes. This was not entirely unexpected since the wastes, while not containing suspended material, probably did contain a significant amount of soluble and colloidal non-oxidizable material, which could be adsorbed on the sludge surface during aeration. The alcohols, on the other hand, were pure compounds, so that any sludge accumulation would be a result of cell synthesis during oxidation by the sludge.

Practical Applications

While marked improvement in oxidation rate resulted from use of acclimatized seed material with even the most difficultly oxidized materials, such as chewing gum waste and isopropylalcohol, it was nevertheless true that the data obtained with normal sewage seeding did give an accurate picture of the relative treatability of the particular waste.

The fact that acclimatization is so readily accomplished indicates that results obtained with normal sewage seeding can only be considered as the initial step in evaluating the oxidation characteristics of a particular waste or organic compound. Use of activated sludge may materially reduce the time required to determine the strength of a particular waste sample, whether it be raw or treated waste. Such a seed will detect not only variations in waste strength, but it may also detect the presence of toxic materials, etc. Conversely, a standard waste material typical of the waste being treated in a particular

waste disposal plant may be used regularly to check the activity of seed material, such as activated sludge or dispersed growth seed, taken from the disposal plant treatment unit.

Therefore, from the standpoint of process control, as well as evaluation of process sewer or stream load, use of normal sewage seeding should at least be supplemented with measurements using acclimatized seed. While such a procedure does not lend itself to universal standardization, as does the standard B.O.D. dilution procedure, it can be adapted readily to the particular application by use of the material presented herein and elsewhere.

The data previously given demonstrate how oxidation rate measurements can be used to predict the relative effectiveness of various treatment methods. In all cases, acclimatized activated sludge produced higher oxidation rates and more rapid B.O.D. removal than dispersed growth seed. This is substantial evidence for the superiority of the former as waste treatment procedure from the standpoint of B.O.D. removal efficiency at comparable loadings. Use of the foregoing method provides an initial rapid screening of aerobic waste treatment procedures prior to further pilot-plant work where such is considered necessary.

Summary and Conclusions

A comparative study was made of the effect of a number of seed materials on the oxidation of industrial wastes and organic compounds. The types of seed used included normal and acclimatized activated sludge, normal sewage, and dispersed growth seed, both mixed and settled.

The following conclusions were reached:

1. In general, the seed materials could be ranked in decreasing order of effectiveness as: acclimatized activated sludge, mixed dispersed growth, settled dispersed growth, normal activated sludge, and normal sewage seed.

2. Differences in oxidizability of several industrial wastes using the same seed could only be attributed to differences in chemical composition as related to metabolic activities of the particular microorganisms concerned.

3. Significant differences exist in oxidizability of the four lower alcohols. Similar differences may exist between members of other homologous organic groups.

4. Differences between sludge accumulation rates during oxidation of alcohols and industrial wastes can be attributed to the fine composition of the former as compared with the presence of non-oxidizable soluble organic materials in the latter.

5. Where a given waste or compound was less readily oxidized than others using a particular seed, the same phenomenon was observed regardless of the type of seed used.

6. The ease with which acclimatization is accomplished suggests that such seed should be more widely used both for waste load measurement and process control (where biological aeration is used as the treatment process).

7. It may be expected, for the wastes studied, that activated sludge treatment will be more effective than dispersed growth aeration.

8. The procedures described can be used for rapid initial screening of aeration treatment methods prior to further pilot-plant evaluation.

Acknowledgment

The work described herein was performed under a research grant from the Division of Research Grants and Fellowships, National Institutes of Health, U. S. Public Health Service.

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EDUCATION AND CAREER STIMULATOR

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Industrial Wastes

APPLICATION OF BIOLOGICAL TREATMENT TO INDUSTRIAL WASTES *

I. Kinetics and Equilibria of Oxidative Treatment

By Roy F. Weston and W. W. Eckenfelder

Respectively, Sanitary Engineer, The Atlantic Refining Co., Philadelphia, Pa., and Partner, Weston, Eckenfelder and Hood, Inc., Paterson, N. J.

Oxidative biological treatment is provided to remove organic materials from waste waters. When such treatment is required by industry, it is expected that the facilities provided will accomplish the desired objective at minimum cost. The dearth of operating experience and design data generally makes it advisable to conduct both bench-scale and pilot-plant studies to acquire needed design information. The normal scatter of the experimental data and the restricted range of operating conditions make the prediction of full-scale performance hazardous unless there is available a sound theoretical basis for establishing correlation.

It is the purpose of this part of the paper to propose a basic theory to explain the behavior of oxidative biological treatment, to evaluate experimental data in the light of these theoretical considerations, to indicate the type of information essential to obtain a better understanding of biological treatment, and to suggest areas of needed research. The second part will discuss the practical application aspects of the problem.

It is proposed that: (a) in the course of oxidative biological treatment, organic matter is removed from waste waters as an essential and integral part of cell growth and maintenance; (b) a part of the carbon content of the organic matter removed is synthesized to biological cells, the balance being oxidized to provide the energy to sustain life and to permit synthesis; and (c) the reactions of biological oxidative treatment follow the laws of chemical stoichiometry and thermochemistry.

Stoichiometry

It is theorized that organic matter is removed from solution by reaction with enzymes associated with biologically active slimes or sludges. Suspended organic matter is removed by coagulation, entrainment, adsorption and other means. In the presence of enzymes, produced by living organisms, a part of the organic matter removed is oxidized and a part is synthesized to cell material. In turn, the cell material is oxidized to carbon dioxide and water.

These three reactions are illustrated by the following material balance equations:

Organic Matter Oxidation

$$C_xH_yO_z + (x + y/4 - z/2)O_2 \xrightarrow{\text{enzyme}} xCO_2 + y/2\ H_2O - \Delta H \quad (1)$$

* Presented at 27th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Cincinnati, Ohio; Oct. 11–14, 1954.

Cell Material Synthesis

$$n(C_xH_yO_z)+nNH_3 + n(x+y/4-z/2-5)O_2 \xrightarrow{\text{enzyme}} (C_5H_7NO_2)_n+n(x-5)\,CO_2 + \frac{n}{2}(y-4)H_2O \pm \Delta H \quad (2)$$

Cell Material Oxidation

$$(C_5H_7NO_2)_n + 5nO_2 \xrightarrow{\text{enzyme}} 5nCO_2 + 2nH_2O + nNH_3 - \Delta H \quad (3)$$

The factors x, y and z in Eqs. 1, 2 and 3 may be positive or zero, depending on the type of compound involved. The term ΔH represents the heat of reaction. The generalized equations must be modified for organic compounds containing nitrogen or sulfur.

Eq. 1 is the conventional equation of combustion. If nitrogen is present, it will be oxidized to nitrate; sulfur will be oxidized to sulfate.

Eq. 2 illustrates the synthesis of cell material using ammonia as a source of nitrogen. Cell material is represented by the empirical formula $C_5H_7NO_2$, suggested by Hoover (1) as representative of the ratio of the primary element constituents of activated sludge. It is representative of the statistical average composition of the complex organic compounds constituting cell material.

In accordance with Eq. 3, the ultimate B.O.D. of cell material would be 1.42 grams per gram. If the volatile solids content of activated sludge is cell material, the ultimate B.O.D. and

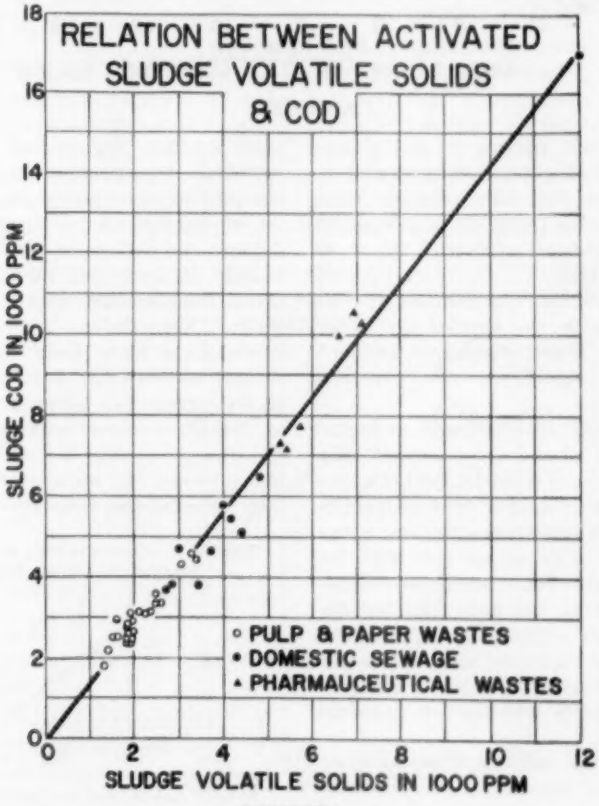

FIGURE 1.

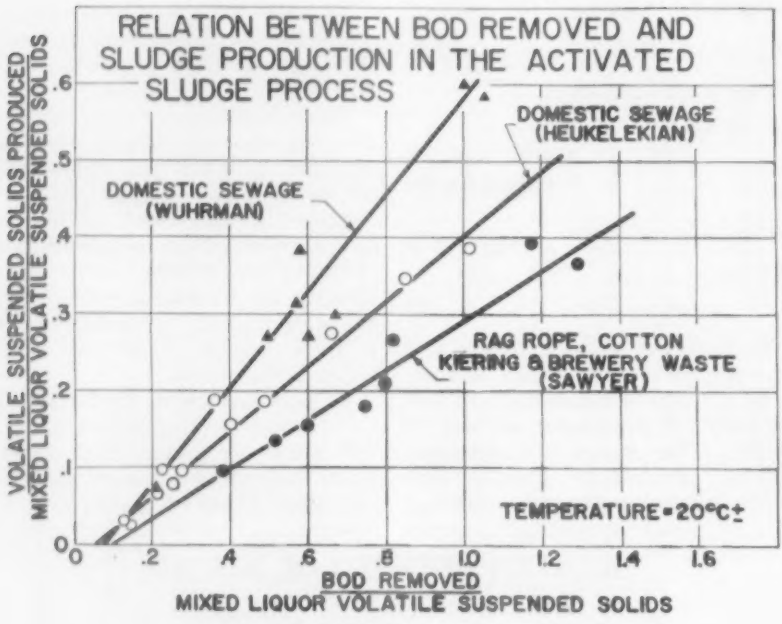

FIGURE 2.

C.O.D. of this portion of the sludge should be 1.42 grams per gram. Figure 1 shows that this relation holds true within the limits of experimental error for several different types of activated sludges. It is recognized that the chemical composition of cells will vary with the species and stage of growth. These variations are normally not significant for practical purposes.

The heat of combustion of activated sludge used in the treatment of milk waste was found to be 10,300 B.t.u. per lb., of volatile solids. The characteristics of two sludge samples are given in Table I. This agrees well with the value of 10,000 B.t.u. per lb. of volatile solids reported by Fair (2) for domestic sewage activated sludge. Available evidence indicates that reasonable confidence may be placed in the proposed empirical formula for practical use.

The material balance chemical equations and the laws of thermochemistry indicate that a definite ratio should exist between the amount of B.O.D. removed, the portion oxidized, and the portion synthesized for any given set of conditions. In practice, it is difficult to determine these relations exactly because cell material is oxidized concurrently with that of the waste. Nevertheless, reasonably good correlations have been obtained by several workers (3)(4)(5). Figure 2 shows correlations between the amount of B.O.D. removed and the quantity of sludge produced. Gellman and Heukelekian (6) have obtained excellent correlations between B.O.D. re-

TABLE I.—Characteristics of Activated Sludge[1] (Dry Solids Basis)

Sample	N (%)	Vol. Sol. (%)	Ash (%)	Heat Value (B.t.u.)		Harvest Time After Feeding (hr.)
				Per lb.	Per lb. Vol. Sol.	
1	9.49	91.44	8.56	9,369	10,246	24
2	10.34	90.79	9.21	9,370	10,321	6

[1] Sample and N and ash analyses by S. R. Hoover, Eastern Regional Laboratory, USDA.

moved and sludge produced for several different types of industrial wastes.

The quantity of oxygen utilized per pound of B.O.D. removed as obtained from a continuous pilot-plant unit is shown in Figure 3. Although the waste and sludge are highly oxidized, the correlations are good. The variations in the data observed are probably due to the fact that the system was not in the same state of equilibrium at the time of each observation.

Available experimental data indicate positively that the amount of cell material synthesized and the amount of organic material oxidized are directly proportional to the amount of B.O.D. removed. The thermochemistry of the synthesis reaction affords a means of estimating the portion of removed B.O.D. that is utilized for synthesis.

Thermochemistry of Synthesis

Using the chemical formula for cell material and experimental heat of combustion data for sludge volatile solids, it is possible to estimate the heat of formation of activated sludge volatile solids as 27.3 kilocalories per empirical mole ($C_5H_7NO_2$). The heat of formation per pound of sludge volatile solids is calculated to be 435 B.t.u. When the heat of formation of cell material is known, it is possible to estimate the type of reaction involved in the synthesis of cell material from any given chemical source. If the cell synthesis reaction is endothermic and isothermic, energy must be supplied from Eq. 1 to make the reaction possible. If the synthesis is exothermic, energy is supplied by the reaction. Tamiya (7) states that all cell synthesis reactions are exothermic. The exact quantitative relations can be determined by experiment only. They may be variable depending upon the specific environment.

Thermochemical data on various chemicals are given in Table II. The enthalpy of combustion of a wide variety of compounds, based on oxygen demand, varies but slightly. Columns 4, 5 and 6 give, respectively, the estimated maximum conversion of ultimate B.O.D. to sludge, the estimated minimum fraction of the compound that would be oxidized in the process of producing sludge, and the quantity

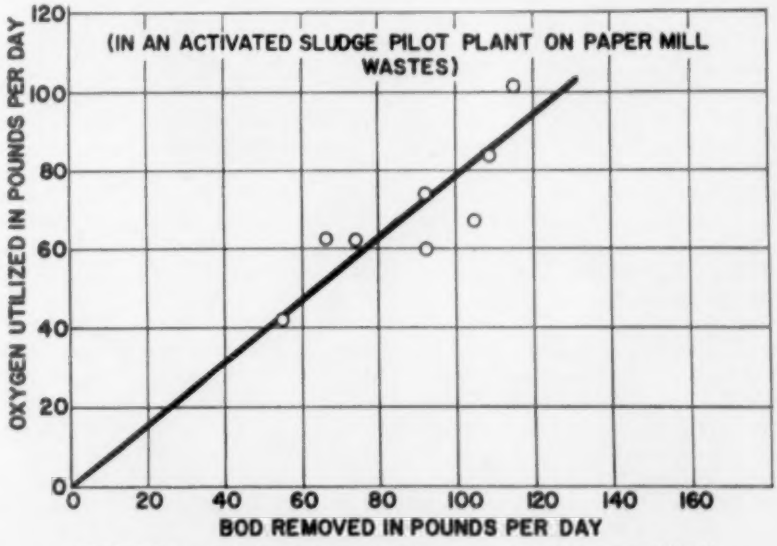

FIGURE 3.—Relation between B.O.D. removed and oxygen utilized.

TABLE II.—Conversion of Ultimate B.O.D. to Sludge

Compound	Enthalpy of Combustion per Gram O_2 Demand (kcal./g.)	Type of Reaction for Max. Conversion of Carbon to Sludge	Oxygen Demand per Gram Sludge (g.)	Probable Minimum Compound Oxidized to Form Sludge (%)	Probable Minimum Oxygen Utilized per Gram Sludge (g.)	Compound Oxidized (%)[1]	
						5 Hr.	24 Hr.
n-propyl alcohol	3.34	Endothermic	2.69	21.0	1.28	—	—
iso-butyl alcohol	3.32	Endothermic	2.67	20.5	1.25	—	—
Benzoic acid	3.22	Endothermic	1.54	1.7	0.10	—	—
Salicylic acid	3.32	Endothermic	0.21	4.2	0.16	—	—
Formic acid	3.94	Exothermic	1.54	8.1	0.13	19.8	39.9
Acetic acid	3.24	Exothermic	1.79	5.1	0.33	4.6	18.7
						21.6	57.1
Tartaric acid	3.53	Exothermic	2.76	23.1	1.35	3.5	29.3
						25.0	80.3
Sucrose	3.52	Exothermic	3.82	11.10	2.42	9.1	7.1
Glucose	3.52	Exothermic	1.92	11.2	0.5	7.4	10.1
Para-toluene sulfonic acid	3.10	Exothermic	3.13	23.2	1.72	—	—
Activated sludge	4.04	—	—	—	—	—	—
Lactose	3.85	Exothermic	1.70	16.7	0.28	15.4	24.8
Methane	3.32	Endothermic	4.09	30.8	2.67	—	—
Ethane	3.33	Endothermic	3.38	26.8	1.97	—	—
Propane	3.32	Endothermic	3.14	24.9	1.73	—	—
n-Butane	3.31	Endothermic	3.03	23.8	1.61	—	—
n-Pentane	3.30	Endothermic	2.92	22.3	1.50	—	—
Acetylene	3.88	Endothermic	2.20	19.5	0.79	—	—
Ethylene	3.51	Endothermic	2.76	23.1	1.35	—	—
Naphthalene	3.21	Endothermic	1.77	3.8	0.35	—	—
Benzene	3.25	Endothermic	1.94	8.45	0.52	—	—
Toluene	3.24	Endothermic	1.84	11.1	0.63	—	—
Phenol	3.34	Endothermic	1.7	2.97	0.29	—	—
Methyl alcohol	3.62	Endothermic	2.80	24.30	1.39	0.5	14.6
Ethyl alcohol	3.40	Endothermic	2.71	21.80	1.3	3.7	24.3
Methyl ethyl ketone	3.35	Endothermic	2.34	16.7	0.92	—	—
Acetone	3.34	Endothermic	2.21	14.65	0.8	—	—

[1] Data of Placak and Ruchhoft (8).

of oxygen required from an external source in converting the compound to sludge.

In the case of compounds producing sludge by an endothermic reaction under isothermic conditions, it is theorized that the reaction can occur if energy is supplied by the oxidation of the compound (7). It is presumed that the amount of energy required is only equal to that essential to make up the deficiency of energy in the synthesis equation; that is, enough to attain a heat balance. In the case of some of the exothermic reactions, it would be thermochemically possible to produce sludge without the utilization of oxygen or the formation of carbon dioxide. The data of Placak and Ruchhoft (8) indicate that the activated sludge process does not synthesize additional sludge without the utilization of oxygen. Therefore, the probable minimum value for percentage of the compound oxidized has been calculated on this basis. The quantity of oxygen required to convert a compound to sludge has been arbitrarily taken as the minimum whole number of moles of oxygen required to produce a mole of sludge. No information is available as to the minimum heat of reaction necessary to produce sludge. Therefore, it is not possible to estimate actual quantities but it is only possible to estimate probable minimum quantities.

Experimental data obtained by

others (8) are shown in Column 6. Data for mixed wastes indicate that 25 to 50 per cent of the B.O.D. removed is oxidized. Available data indicate the definite possibility of agreement between theoretical and practical sludge production data. Additional research to obtain fundamental data on free energy changes, during the synthesis reaction, may make it possible to derive information of practical value.

Type of Reaction

In accordance with the theory, reaction is intimately associated with cell growth. Therefore, the kinetics of cell growth and decay should control the rate of reaction.

Since conventional biological treatment facilities provide an active biological culture and food for sustaining that culture, it is reasonable to presume that the system will follow the classical laws of cell growth and decay. The various phases of a classical batch culture experiment are shown in Figure 4.

There are nine different phases of growth. First, there is the initial stationary or "lag" phase, after the addition of nutrient, during which time there is substantially no growth. This is followed by an accelerated growth phase (AB), during which the rate of growth increases to a maximum. The maximum or logarithmic growth rate (BC) is dependent on the generation time; that is, reproduction time of the cells in the culture. As the food supply is exhausted, a phase of negative growth acceleration is observed (CD). This is followed by a maximum stationary growth phase (DE), in which the rate of death is equal to the rate of growth. In a relatively short time, the rate of death exceeds the rate of growth and there is an accelerated decrease in cell population (EF). This is followed by a logarithmic death phase (FG), in which the rate of death of organisms is substantially greater than the rate of growth. This is probably the endogenous respiration phase of activated sludge activity, during which the sludge is oxidized to carbon dioxide, water, and ammonia. In practice, a change in the organism population of the sludge occurs at about this time. The new populations probably use the old as a source of food. The logarithmic death phase is followed by a phase of readjustment (GH), dur-

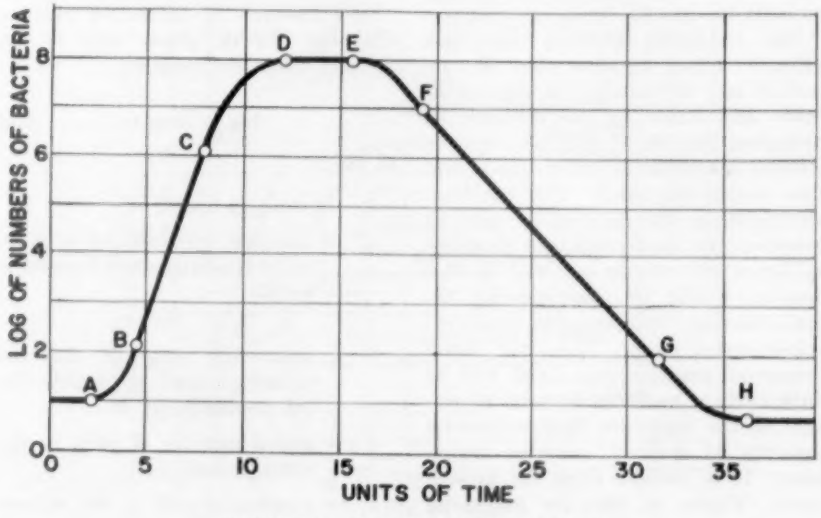

FIGURE 4.—Growth phases in a culture.

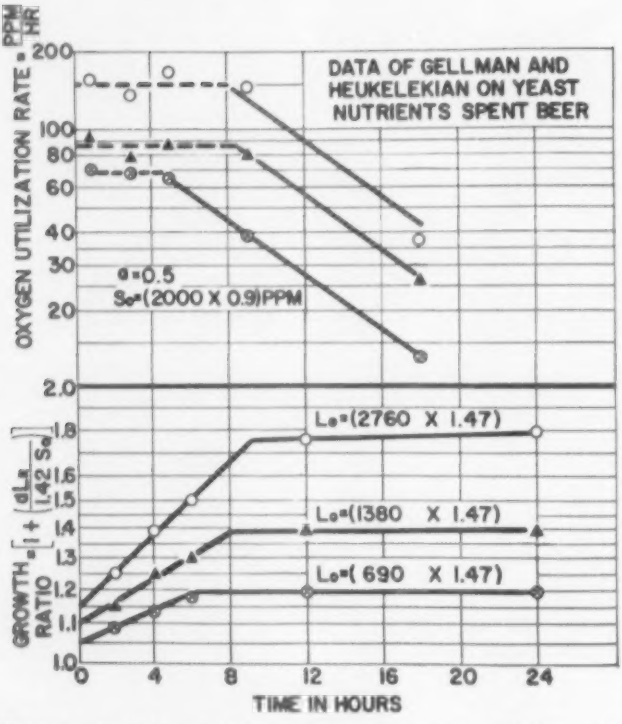

FIGURE 5.—Variation of sludge growth and oxygen utilization with time.

ing which time the rate of death decreases. Finally, a dormant state is reached in which there is substantially no activity.

The complete oxidation equations (Eqs. 1, 2 and 3) show that organic matter may be oxidized to carbon dioxide and water in the presence of biological growth, if sufficient time is allowed to synthesize cell material and then oxidize the same. This has been confirmed in the laboratory and in practice. In most cases, the complete oxidation of organic material in this manner would be uneconomical because the time requirements would involve several days. Therefore, waste treatment practice uses fixed bed or fluid culture methods to take advantage of the high-rate food utilization capacity of actively growing organisms. It is obvious from the growth curve (Figure 4) that the maximum rate of removal of organic material would be associated with the logarithmic growth phase. This phase occurs immediately on addition of nutrient (waste) to an active culture. The log growth phase may be expressed mathematically as

$$\log \frac{C}{C_0} = k' t \ldots\ldots\ldots (4a)$$

in which

t = time, in hours;

k' = reaction constant for a given set of conditions and is equal to $\frac{0.693}{g}$;

g = generation time of the cell (time required to double the cell population);

C_0 = initial number of cells in the culture; and

C = number of cells in the culture at time t.

If the number of cells in the culture is expressed in terms of weight per unit of weight (that is, p.p.m.), the equation may be rewritten as

$$\log \frac{S}{S_0} = k\,t \ldots\ldots\ldots (4b)$$

in which

S_0 = initial cell material concentration, in p.p.m. in the reacting solution; and

$S = S_0 + \Delta S$ = cell material concentration, in p.p.m., at any time, t, in which ΔS is the incremental increase in concentration.

The cell material concentration should be expressed in terms of volatile solids, if possible. It is the volatile matter content— that is, ($C_5H_7NO_2$) —that is indicative of active cell material. The reacting solution is the solution in contact with the culture. In practice, it would be the mixed liquor of activated sludge or the forward flow plus recycle of the trickling filter.

By theory, the amount of cell material produced is proportional to the amount of organic material (B.O.D.) removed. It is proposed that

$$\Delta S = \frac{a\,L_r}{1.42} \ldots\ldots\ldots (5)$$

in which

L_r = the ultimate B.O.D. concentration removed by S; expressed as p.p.m.;

a = fraction of ultimate B.O.D. synthesized; and

1.42 = the theoretical factor for converting ultimate B.O.D. to cell material.

It follows that

$$\log\left(1 + \frac{a\,L_r}{1.42\,S_0}\right) = k\,t \ldots (6)$$

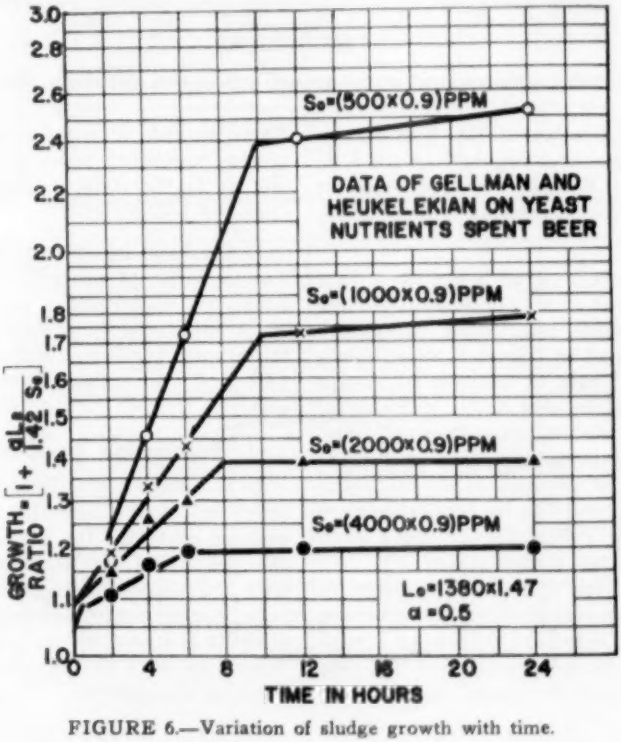

FIGURE 6.—Variation of sludge growth with time.

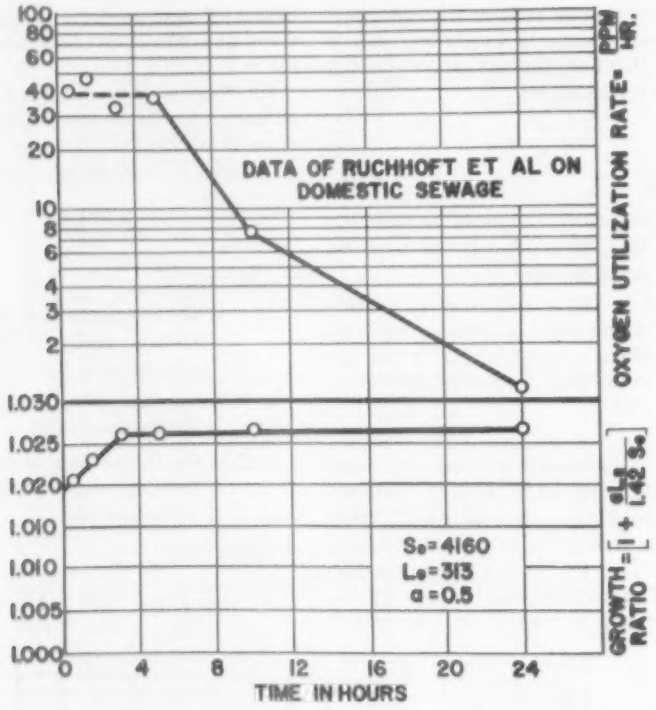

FIGURE 7.—Variation of sludge growth and oxygen utilization with time.

The application of Eq. 6 to experimental data is shown in Figures 5, 6, 7 and 8. Several points of interest should be noted relating to these plots, as follows:

1. The data of all plots show that the removal of B.O.D. follows the log growth phase law. This is further substantiated by Figure 8, which shows the actual rate of increase of sludge volatile solids (log S/S_o) to be equal to the calculated "growth ratio" rate.
2. All experiments show that there is an initial removal of B.O.D. The removal appears to be proportional to the initial concentrations of B.O.D. and activated sludge solids.
3. The rate of reaction appears to increase as the L_o/S_o ratio increases.
4. Each reaction proceeds at a relatively rapid rate until some limiting residual B.O.D. value is reached. Then the rate of reaction sharply decreases to a much lower level. This is similar to the state of equilibrium of chemical reactions.

If the basic log growth phase equation is to be of practical value, it is necessary to develop a theory to explain satisfactorily the effects of the important variables, B.O.D. loading (L) and cell material concentration (S).

Reaction Equilibria

It is believed by Hoover (9) that activated sludge contains an initial enzyme content. On admixture with the waste the initial enzyme reacts with the waste substrate to form an organic matter-enzyme complex. This complex is stored by the organism for future use as a source of energy and material for growth.

The theory relative to the formation of an organic matter-enzyme complex may be illustrated as follows (10):

B.O.D. + Enzyme ⟶ B.O.D.-Enzyme Complex . . (7)

B.O.D.-Enzyme Complex ⟶ Enzyme + End Products . . (8)

If such reactions occur they must be related to the material balance equation (Eq. 3), which indicates a complex reaction. However, research data have demonstrated that the reaction is not controlled by each reacting constituent. It has been shown that the rate of reaction is practically independent of dissolved oxygen concentration above a limiting minimum value of about 0.5 p.p.m. (1). Also, it has been shown that normal concentrations of a source of nitrogen above a minimal value have substantially no effect on the reaction (11). The end products of reaction, carbon dioxide and water, should have practically no effect on the reaction. This may be expected because the circumstances of use prohibit the accumulation of carbon dioxide. The quantity of water produced by the reaction is normally infinitesimally small compared to the quantity of water present. Therefore, new cell material is the only end product of significance.

The foregoing facts make it possible to rationalize that Eqs. 7 and 8 represent the significant relationships as-

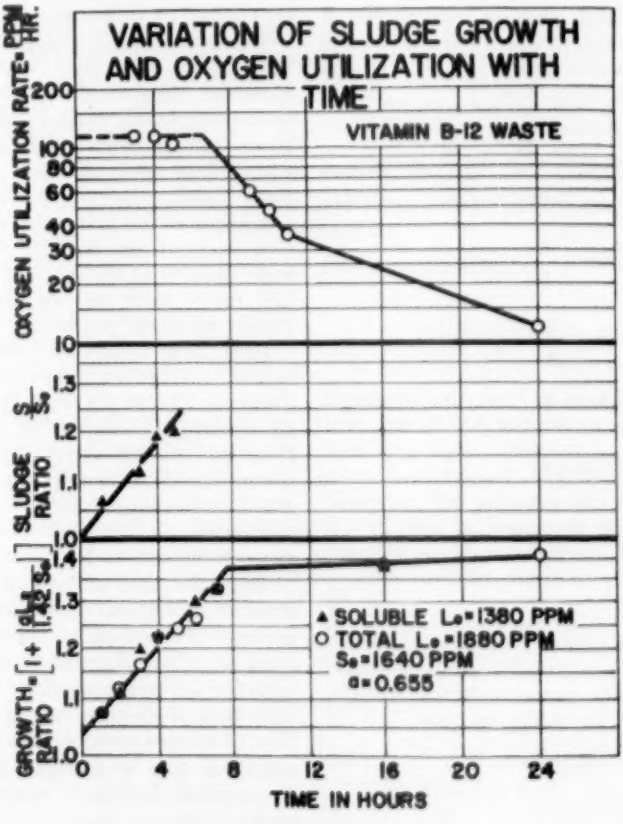

FIGURE 8.

sociated with biochemical reactions in most waste treatment systems. Under conditions of oxygen or nitrogen deficiency, phosphate deficiency, or toxic conditions, these generalizations will not apply. Neither will they apply to conditions of confinement where carbon dioxide can accumulate or in which the amount of water produced by the reaction is relatively large in respect to the total water content.

For normal conditions (that is, dilute solutions), the following simplified equations are proposed.

Initial Reaction

From Eq. 7,

$$L_0 + E_0 \longrightarrow C \ldots\ldots (9)$$

in which

E_0 = initial enzyme concentration ($e\,S_0$), in which e is the enzyme concentration per unit of cell material; and

C = complex concentration.

In accordance with the mass law,

$$(L_0\,E_0)K_1 = C\,K_2 \ldots\ldots (10a)$$

and

$$C = \frac{K_1}{K_2}\,(L_0\,E_0) \ldots\ldots (10b)$$

or

$$C = \frac{K_1}{K_2}\,(L_0\,e\,S_0) \ldots\ldots (11)$$

The amount of complex produced (that is, the amount of B.O.D. removed in the initial reaction) is proportional to the initial B.O.D., L_0 and the enzyme content of the reacting cell material. This relation presumes an activity coefficient of unity for each constituent. It will apply to dilute solutions only.

Since

$$C = p\,L_{ri} \ldots\ldots (12)$$

in which p is a proportionality constant and L_{ri} is the concentration of B.O.D. removed in the initial reaction,

$$L_{ri} = b\,L_0\,S_0 \ldots\ldots (13)$$

in which

$$b = \text{the constant, } \frac{K_1\,e}{K_2\,p}.$$

The initial reaction phase has been studied by Eckenfelder (12), Keefer and Meisel (13), Katz (14), and Kountz (15). Their data indicate that the initial reaction is completed in 10 to 20 min., it being possible to remove as much as 75 per cent or more of the initial B.O.D. in that time. The excellent quantitative data of Katz clearly demonstrate that the B.O.D. removal during the first 10 to 20 min. of contact is at a much higher rate than after 20 min. of contact. This has been confirmed by Kountz. The rate of reaction is probably due to the efficiency of contact during mixing. The relations observed by Katz (14) demonstrated that the concentration of B.O.D. remaining after 20 min. of contact with a given concentration of activated sludge was a constant portion of the initial B.O.D. This is in agreement with Eq. 13. However, Katz concluded that systems containing higher concentrations of activated sludge were relatively less reactive than those of lesser concentration. This observation is possible, according to the principles of physical chemistry, if the activity of the enzyme is concentration dependent in the range used in the experiments (1,000 to 6,000 p.p.m.)

Data from continuous flow, bio-flotation pilot-plant experiments are shown in Figure 9 (19). The value of L_a varied from 57 to 230 and of S_a from 268 to 524 p.p.m. in these experiments. Insufficient data are available to determine the effect of S_a concentration on activity. In general, these data confirm Eq. 13.

Since the time of passage of waste through a high-rate trickling filter is generally 15 to 25 min., initial reactive capacity of the filter slimes must have a major influence on filter efficiency. The data of Keefer and Kratz (16), Mau (17), and many others have demonstrated that a constant portion of the applied B.O.D. is removed by a trickling filter. Such a relationship applies over a relatively wide range

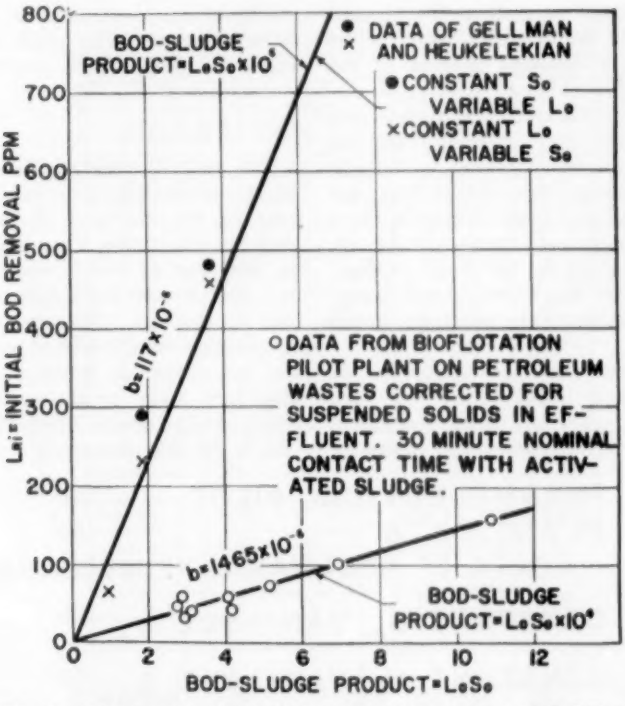

FIGURE 9.—Relation of initial B.O.D. removal to product of B.O.D.-activated sludge concentration.

of loadings. Since S_o is practically a constant for a trickling filter, this relation is in agreement with Eq. 13. The theory proposed herein is also consistent with that proposed by Velz (18).

Research data of Keefer and Meisel (13), Katz (14), Kountz (15), Ruchhoft *et al.* (20), and Gellman and Heukelekian (6) all clearly demonstrate the possible effects of sludge handling and acclimatization on reactive capacity. The reactive capacity of various activated sludges may vary many fold, depending on the age and on the handling and acclimatization conditions. The range in the value of the coefficient b may vary from 3×10^{-6} or less to 1×10^{-3} or more.

Initial reaction rates and capacities are subjects of considerable economic importance in waste treatment. They warrant much additional research.

Synthesis Equilibrium

From Eq. 8,

$$C \longrightarrow \Delta S + E_o \ldots\ldots (14)$$

In accordance with the mass law,

$$C\,K'_1 = K'_2(\Delta S\,E_o) \ldots\ldots (15a)$$

or

$$C = \frac{K'_2}{K'_1}(\Delta S\,E_o) \ldots\ldots (15b)$$

By Eqs. 11 and 15

$$C = \frac{K_1}{K_2}(L_o\,E_o) = \frac{K'_2}{K'_1}(\Delta S\,E_o) \ldots (16a)$$

or

$$C = \frac{K_1}{K_2}(L_o\,e\,S_o) = \frac{K'_2}{K'_1}(\Delta S\,e\,S_o) \ldots (16b)$$

and

$$\Delta S\,S_o = \frac{K_1 K'_1}{K_2 K'_2}(L_o\,S_o) \ldots (16c)$$

Then, from Eq. 5,

$$L_r S_o = \frac{1.42}{a}\,K\,L_o S_o \ldots\ldots (17)$$

For any given system, the amount of B.O.D. removed at equilibrium should be a constant portion of the amount of B.O.D. applied. No correction has been made for enzyme production that may occur during the synthesis of cell material. Methods for evaluating this factor are not available at this time. However, since enzyme production is probably directly proportional to L_r, the basic relation illustrated by Eq. 17 would still apply. Only the value of the constants would change.

Data from the investigations of Gellman and Heukelekian (6) are shown in Figure 10, which also shows data from a continuous activated sludge pilot plant. These data and observations on other pilot plants and full-scale plants give practical substantiation of Eq. 17.

Rate of Reaction

The rate of reaction is dependent on the generation time of the organisms in the culture. It is believed that the generation time is dependent on the rate at which essential foods can diffuse into the appropriate portion of the cell. Therefore, the rate of reaction would be proportional to the concentration gradient across a boundary layer or the osmotic pressure gradient across a membrane (21) (22). If this theory is correct, the

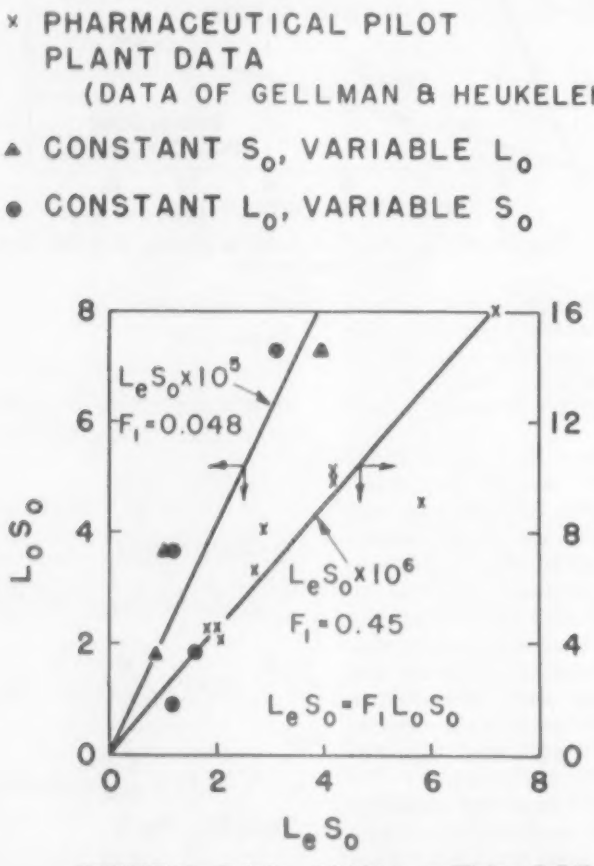

FIGURE 10.—Relation of initial to equilibrium B.O.D.

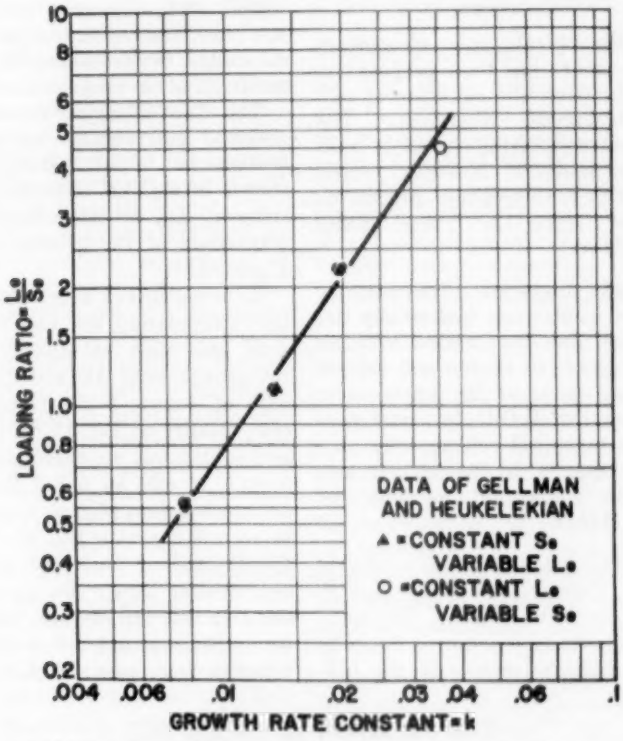

FIGURE 11.—Effect of B.O.D.-sludge ratio on growth rate.

reaction constant k of the log growth phase equation would be proportional to the concentration per unit of area. The rate of reaction should vary as some function of L_o/S_o if the concentration on the cell side of the membrane is practically zero. This assumption is reasonable (21)(22). The relationship between k and L_o/S_o is shown in Eq. 19. The constant, m, is indicative of the permeability of the cell and the rate of diffusion. The exponent, n, establishes the relationship between generation time and food concentration. The equation applies only to that range in which generation time is food concentration dependent. At high food concentrations, k should approach a constant (23).

The data of Figure 11 confirm the contention that the rate of reaction for any given cell concentration is dependent on the initial B.O.D. concentration.

Eq. 6 may be rewritten as follows to correct for the initial reaction and the effects of B.O.D. and sludge concentrations on the reaction constants:

$$\log\left(1+\frac{a\,L_r}{1.42S_0}\right)=k\,t+C \quad \ldots (18)$$

in which

$$k=m(L_0/S_0)^n \quad \ldots (19)$$

and

$$C=\log\left(1+\frac{a\,b\,L_0}{1.42}\right) \quad \ldots (20)$$

Then

$$\log\left[\frac{\left(1+\frac{a\,L_r}{1.42S_0}\right)}{\left(1+\frac{a\,b\,L_0}{1.42}\right)}\right]=m(L_0/S_0)^n\,t \quad \ldots (21)$$

Discussion

A philosophical and elementary technical theory has been proposed to explain, in part, the behavior of oxidative biological treatment. The theory and supporting evidence indicate that oxidative biological waste treatment is a three-phase process as shown in Figure 12. These phases are as follows:

1. Initial high-rate removal of B.O.D., on contacting biologically active sludge, due to reaction between the enzymes of the sludge and the organic constituents of the waste.
2. Removal of B.O.D. in direct proportion to biological cell growth.
3. Oxidation of biological cell material with concurrent low-rate removal of B.O.D.

The initial reaction phase is shown as AC in Figure 12. This phase is completed in 10 to 30 min. The magnitude and rate of reaction is dependent on the characteristics of the biological sludge (enzyme content, activity, etc.), the concentration of biological sludge, the concentration of organic matter, and the effectiveness of mixing.

The effect of enzyme content and cell material and organic matter concentrations on initial B.O.D. removal is shown in Eq. 13. The initial B.O.D. removal, L_{ri}, is determined from the magnitude of the growth ratio (AB, Figure 12).

L_{ri} is the B.O.D. removal determined by extrapolating the line CD to zero time and then calculating L_r using the growth ratio AB and Eq. 18. The data of Figure 9 illustrates the general validity of Eq. 13 for both batch and continuous activated sludge treatment. It will be noted that the experimental data plot as a straight line in accordance with Eq. 13. At higher B.O.D. and/or activated sludge concentrations, it can be expected that the relation will deviate from linearity. The amount of initial B.O.D. removal per unit of $L_o S_a$ product

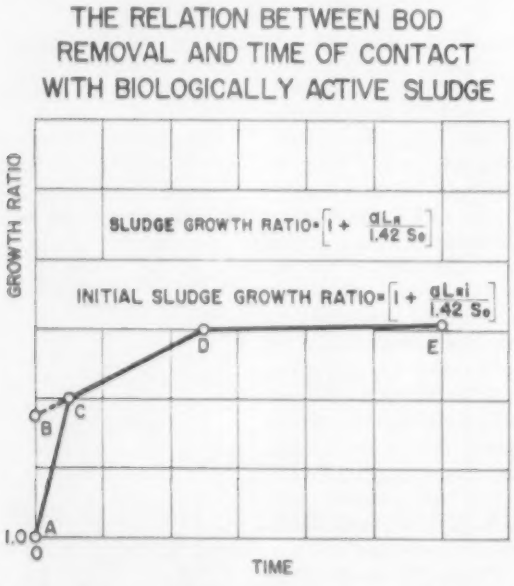

FIGURE 12.—Relation between B.O.D. removal and time of contact with biologically active sludge.

should drop off because the activity of L_oS_o, or both, may gradually decrease to values less than 1.0. The relationship should follow the basic laws of physical chemistry.

The intensity of mixing can influence both the magnitude and rate of reaction. The effects of mixing will be discussed in Part II.

The initial removal of B.O.D. is of considerable economic importance in industrial waste treatment. It is important because it provides the means of obtaining required treatment with the minimum size structure. Considerable research is justified to determine the factors influencing the initial B.O.D. removal capacity of activated sludge. Some of the practical aspects of this phase of the problem will be discussed in Part II.

The second phase of the treatment reaction is characterized by adherence to the log growth phase law of cell growth. It is shown by CD (Figure 12). After the complete reaction of all enzyme initially associated with the biological sludge (that is, the first phase of treatment), subsequent removal of B.O.D. is intimately associated with the synthesis of cell material. For any given organic compound a definite portion is synthesized to cell material (that is, sludge, S) and the remainder is oxidized. This makes it possible to estimate sludge production (ΔS) from B.O.D. removal (L_r) data. The relationship between ΔS and L_r is shown in Eq. 5. The log growth law using L_r data is shown in Eq. 6. The data of Figures 5, 6, 7 and 8 and that of other workers (20) (24) illustrate the validity of this correlation.

The limited data available indicate that the portion of any specific compound that is synthesized (that is, a) can be predicted using the principles of thermochemistry. Predicted minimum conversions of B.O.D. to cell material for various pure compounds are given in Table II.

For convenience of illustration and analysis, the quantity $\left(1 + \frac{a\,L_r}{1.42\,S_o}\right)$ has been shown on Figures 5, 6, 7, 8 and 12 as "growth ratio." This is a hypothetical value because it incorporates the initial B.O.D. removal, L_{ri}. According to the theory, the B.O.D. removed initially forms an enzyme-B.O.D. complex. Cell material is converted later. Therefore, the true "growth ratio" is that shown as the left side of Eq. 21.

As shown in Figures 5, 6, 7 and 8, growth proceeds at a constant log rate to some limiting residual B.O.D. concentration in the treated waste. The rate of growth then decreases abruptly. The abrupt change in growth rate shown in Figures 5, 6, 7, 8 and 12 is typical of the cultural behavior of bacteria (21). This phenomenon is similar to the equilibrium of chemical reaction. Although equilibrium, in a chemical sense, is not attainable in a dynamic biological system, for all practical purposes equilibrium has been reached at the limiting residual B.O.D. concentration. The B.O.D. removal data of Garrett and Sawyer (24) confirm the log growth phase and its abrupt ending. Their data show that the rate of oxygen utilization increases with time. This observation is in agreement with the log growth law in that the absolute rate of increase of cell material increases with time. The oxygen utilization rates of Figures 5, 7 and 8 drop off abruptly at the time of cessation of the log growth phase. Garrett and Sawyer (24) observed this same phenomenon. These observations confirm the need for oxygen in cell synthesis.

The rate of sludge production and concurrent B.O.D. removal is proportional to the initial cell concentration (S_o) and the initial B.O.D. concentration (L_o). A proposed relationship between B.O.D. concentration (L_o), sludge concentration (S_o), and log growth constant (k) is shown in Eq.

19. The relationship observed for the Gellman and Heukelekian (6) data is shown in Figure 11. The observations of Penfold and Norris (25) confirm the fact that the rate of growth is proportional to the food concentration at low food levels. The effect of food concentration on cell generation time as shown by Clifton (23) indicates a logarithmic relationship, as proposed in Equation 19. As the food concentration increases, the generation time approaches a minimum constant value. The constant, k, of Eq. 19 will approach a maximum constant value. Therefore, the relationship of Figure 11 will deviate from linearity at high B.O.D. values.

The third phase of treatment is shown by DE (Figure 12). B.O.D. removal is at a very low rate during this phase. In fact, the B.O.D. may increase on prolonged aeration of 12 to 24 hr. The B.O.D. concentration level at which this phase occurs is a function of the cell material concentration (S_a) and the initial B.O.D. (L_a). This relation is shown by Eq. 17. Experimental evidence of the validity of this relation is shown in Figure 10.

To better illustrate the existence of an equilibrium condition the applied loading-sludge product (L_aS_a) is plotted against the limiting or equilibrium B.O.D.-sludge product (L_eS_a). The equilibrium B.O.D. (L_e) is the ultimate B.O.D. of the organic matter remaining in the waste at the end point of the log growth phase. It is the remaining B.O.D. at point D (Figure 12). The data shown in Figure 10 illustrate the basic relationships of Eq. 17 because $L_e = L_a - L_r$. The relationship shown may deviate from linearity at high loading values. The analysis of additional systems will establish this fact. Operating data from conventional activated sludge plants confirm the linear relationships of Figure 10 (that is, percentage of efficiency remains a constant for relatively wide variations in applied loading).

The dominant characteristic of this phase is the oxidation of the cell material synthesized in the second phase.

All available evidence indicates that cell synthesis and cell oxidation occur simultaneously in phases 1 and 2. Cell oxidation is predominant in phase 3. This is in evidence by a decrease in the volatile solids content of activated sludge on continued aeration. Hoover (26) has referred to this phenomenon as endogenous respiration. A knowledge of the kinetics and equilibria of endogenous respiration plus adequate information on B.O.D. removal, as previously outlined, should make it possible to determine the quantity of active biological sludge that can be sustained in a system. Various aspects of this problem will be discussed in Part II.

It should be noted from Figures 5 and 6 and Eq. 17 that, as long as adequate aeration time is provided to reach the limiting B.O.D. concentration (equilibrium) for any given maximum B.O.D. loading, the efficiency remains a constant for various B.O.D. loadings up to that maximum value. However, as soon as the loadings are sufficiently great that equilibrium cannot be reached in the time available, the efficiency of treatment will decrease as the loading increases. At very high loadings, the initial B.O.D. removal capacity of the sludge in a system may be completely lost. The rate of B.O.D. removal would be controlled by the rate of cell (sludge) growth. The economic implications of these facts warrant study.

The rate of growth of biological sludge and the equilibrium of a treatment system is dependent on temperature. The effects of temperature will be discussed later.

In order to completely understand the kinetics and equilibria of biological treatment systems, it is necessary to know the magnitude and variability

of five different reaction constants, as follows:

1. The sludge synthesis constant, a, of Eq. 5.
2. The initial B.O.D. removal constant, b, of Eq. 13.
3. The log growth rate constants, m and n, of Eq. 19.
4. The limiting or equilibrium B.O.D. constant, K, of Eq. 17.

Research should be conducted to establish the factors influencing the magnitude of these constants for different types of treatment systems. With such information, the designer can provide the most economical process design and the operator can better understand the variabilities of his operations.

Conclusion

A theory has been developed to explain the kinetics and equilibria of biological oxidative treatment systems. A deliberate effort has been made to simplify the problem at the risk of oversimplification. It is recognized that a more rigorous analysis of the problem and additional research may necessitate deviations from linearity for some of the simple relations proposed. Such deviations will follow fundamental laws of physical and biochemistry. More rigorous analyses and additional research pointing out fundamental deviations will positively advance the science of biological oxidative treatment. In the meantime, the theory proposed herein can provide practical assistance to the research worker in the design of experiments; to the designer in determining the economic effects of variations in process design; and to the operator in evaluating the influence of operating variables on plant performance. Some of the practical considerations pertaining to the application of the theory are to be discussed in Part II.

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PROGRESS IN SANITARY ENGINEERS CERTIFICATION PLAN

The Board of Direction of the American Society of Civil Engineers has authorized the Society's underwriting of the general procedure to provide for the certification of sanitary engineers.

The organizations responsible for this activity under the Joint Committee on the Advancement of Sanitary Engineering, with Federation Past President Earnest Boyce as Chairman, include the American Society of Civil Engineers, the American Water Works Association, the American Society for Engineering Education, the American Public Health Association and this Federation.

Under the plan as approved, an American Sanitary Engineering Intersociety Board will be incorporated for the purpose of reviewing the qualifications of applicants and certifying those who meet the Board's standards of proficiency as sanitary engineers. It is hoped that this certification plan will assist in the elevation of the professional status of the sanitary engineer.

Members of the Federation Member Associations may take pride in the Federation's part in this activity. While it may be of limited use to some, the elevation of the professional status is certain to benefit all of those in the field.

The Federation owes a debt of gratitude to its representatives—Ray Lawrence, Dwight Metzler and R. S. Rankin—for their service on the committee.

CITRUS WASTE WATER TREATMENT OF ACTIVATED SLUDGE *

By Marshall H. Dougherty, Richard W. Wolford, and Robert R. McNary

Florida Citrus Experiment Station, Lake Alfred, Fla.

The treatment of waste water continues to be a problem of the citrus processing industry. This study of the activated sludge process has been concerned not only with reducing the noxious properties of the waste, but also with the utilization of the excess sludge that results. Dried sludge appears to have possibilities as an animal feed supplement.

In a study of an anaerobic means of treating citrus wastes (3)(4)(5) it was found that the waste had to be aerated first to remove an interfering substance (peel oil) before methane bacteria could digest the remaining organic matter. Since the employment of an aeration stage was necessary, it seemed logical to investigate a completely aerobic procedure, such as the activated sludge process. It is believed that the results given in this report indicate that this process should be very useful in treating citrus wastes.

Before starting these aerobic experiments, the authors discussed the treatment of citrus wastes with Sanborn and Canham (6). These workers had diluted canned grapefruit juice with water to obtain a solution having about 2,000 p.p.m. B.O.D. and used this as a raw waste in a small-scale laboratory-treatment system. Different amounts of inorganic nitrogen and phosphorus compounds were dissolved in the raw waste to make up for any deficiencies that might be present. The waste was treated in three aeration vessels arranged in series and usually had a detention time of 6 hr. in each, or a total of 18 hr. To keep the process as simple as possible, the settleable solids in the effluent were not recycled to the aeration vessels. On the basis of one to three analyses for each run, the B.O.D. reductions obtained were as high as 97 and 98 per cent. They had difficulty, however, in obtaining an effluent that would clarify readily on standing. The amount of air used apparently was not measured.

Apparatus

The experiments reported here were patterned after the work of Sanborn and Canham as previously described. The major difference was the recycling of solids settled from the effluent to the primary aeration vessel in the manner of the activated sludge system for treatment of municipal sewage. In the first two runs, both phosphorus in the form of trisodium phosphate and nitrogen in the form of sodium nitrate were added to the raw waste in about the proportion recommended by Sanborn. In succeeding runs the amounts of these materials were stepwise reduced until they were both eliminated entirely in the last two runs. The apparatus (Figure 1) consisted of a raw waste supply tank *A*, which held an amount sufficient for one day (16 l.); three 4-l. aeration tanks B_1, B_2, B_3; a settling tank C; and an effluent tank D to catch the effluent. A Sigmamotor pump metered the raw waste to the first aeration tank, from which gravity flow carried it through the other two aera-

* Cooperative research by the Florida Citrus Commission and Florida Citrus Experiment Station. Florida Agricultural Experiment Station Journal Series, No. 353.

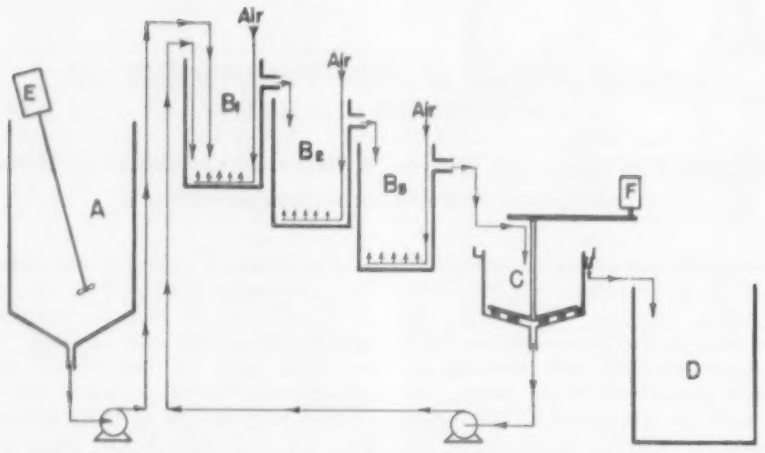

FIGURE 1.—Schematic diagram of laboratory apparatus used for treatment of citrus waste by the activated sludge process.

tion tanks in series and then to the settling tank. Another Sigmamotor pump returned the sludge from the bottom of the settling tank to the first stage of aeration. Both pumps were operated with variable-speed drives. The sludge pump recirculated the settled sludge at the rate of between two and three volumes per volume of raw waste. The effluent overflowed from the top rim of the settling tank to the effluent tank. Each aeration tank received 0.1 c.f.m. of air, measured through a capillary flowmeter and dispersed through perforated 5/16-in. diameter stainless steel tubing.

Several differently designed settling tanks were used, but all operated on the same principle; that is, they were round with a conical bottom, and were equipped with a rotating scraper to move the sludge down to the bottom of the cone, where it was picked up by the pump for recirculation. In runs E, F, G, and H, an improved settling tank was installed. This was a small replica of a standard clarifier having a detention time of approximately 2.5 hr. This device increased the efficiency of the sludge recirculation to the point where only small amounts of sludge were lost with the effluent, thus causing the sludge in the system to build up gradually. To maintain satisfactory settling, the sludge concentration was not allowed to exceed about 16 per cent by volume. Small amounts of sludge were withdrawn each day, the quantity depending on the excess present. In these experiments the percentage of sludge volume was determined by centrifuging a sample for 5 min. at full speed in a graduated centrifuge tube in a clinical-type centrifuge.

Procedure

The raw waste was prepared each morning by diluting orange juice with tap water to the desired concentration. The chemical nutrients, if any, were dissolved in it and a sample was withdrawn immediately for analyses. The data for total and organic solids showed rather large variations, even larger than the 5-day B.O.D. This was due to the fact that the dilutions for the raw waste were based on the degree Brix of the orange juice used. The degree Brix, or so-called "total soluble solids content," is determined either by a refractometer or hydrometer and is little influenced by suspended solids or pulp. Because the

TABLE I.—Analysis of Experiments on Treatment of Citrus Waste Liquors by the Activated Sludge Process

Item	Run A	Run B	Run C	Run D	Run E[1]	Run F[1]	Run G[1]	Run H[1]
Duration of run, days	33	48	39	29	62	25	54	12
Feed, volume (l./day):	16	16	16	16	16	16	16	10
Na_3PO_4 added (p.p.m.)	500	500	250	125	0	0	0	0
$NaNO_3$ added (p.p.m. N)	130	130	65	32.5	32.5	16.5	0	0
Total solids (%)	0.594	0.326	0.275	0.272	0.265	0.243	0.245	0.426
Organic solids (%)	0.503	0.252	0.224	0.238	0.237	0.223	0.231	0.404
Organic solids (lb./day)	0.177	0.091	0.079	0.084	0.083	0.079	0.081	0.089
Loading, org. sol. (lb./cu. ft./day)	0.419	0.215	0.187	0.199	0.196	0.187	0.192	0.210
B.O.D. (p.p.m.)	3129	1701	1628	1832	1933	1598	1865	3095
B.O.D. (lb./day)	0.110	0.060	0.057	0.064	0.068	0.056	0.064	0.069
Loading, B.O.D. (lb./cu. ft./day)	0.260	0.142	0.135	0.151	0.161	0.133	0.151	0.163
pH	5.86	7.07	6.57	6.19	5.65	5.38	5.14	4.63
Effluent:								
Sludge (% by vol.)	3.0	1.2	0.9	2.1	1.6	1.0	0.47	0.50
Total solids (%)	0.297	0.158	0.118	0.143	0.122	0.096	0.078	0.102
Organic solids (%)	0.213	0.087	0.069	0.106	0.097	0.076	0.063	0.082
Organic solids (lb./day)	0.075	0.031	0.024	0.037	0.034	0.027	0.022	0.018
B.O.D. (p.p.m.)	1274	59	77	181	126	49	70	68
B.O.D. (lb./day)	0.045	0.002	0.003	0.006	0.0046	0.0017	0.0025	0.0016
pH	7.08	8.11	7.97	7.66	7.59	7.51	7.42	7.58
Removal, total solids (%)	49.3	49.2	57.4	46.9	52.9	63.7	66.2	78.0
Std. deviation	12.5	14.8	11.4	13.3	14.0	10.7	11.6	7.0
Std. error of mean	2.32	2.47	2.69	3.13	1.98	2.39	1.73	2.21
Removal of org. solids (%)	56.0	66.3	69.0	54.1	59.2	66.0	72.2	79.5
Std. deviation	15.7	11.1	11.5	13.8	11.7	18.0	5.7	4.5
Std. error of mean	2.92	1.85	2.71	3.25	1.66	4.03	0.85	1.42
Removal of B.O.D. (%)	59.7	96.5	95.4	90.2	93.5	96.9	96.3	97.5
Std. deviation	11.6	1.55	4.1	7.8	2.8	0.54	1.4	1.4
Std. error of mean	3.10	0.59	1.45	2.95	0.89	0.22	0.32	0.63

[1] Improved settling device used in these runs.

pulp particles are mostly cellulose, they do not contribute greatly to the B.O.D. determination but, of course, are important in the solids determinations. B.O.D. analyses, as a rule, were made on raw waste and effluent four times each week. The system was not fed on Sundays, although the aeration was maintained as usual.

Results

The results of this investigation are given in Table I. The duration of the runs was not uniform. Runs B, E, and G were extended for longer times in order to be certain that the data represented the conditions of the run. The other runs were less extended to conserve time. Run A, which was definitely overloaded, showed rather low B.O.D. removal, although solids removals were not proportionately affected. The loading was reduced in the succeeding runs. The addition of the trisodium phosphate and sodium nitrate nutrients was gradually reduced in runs C, D, E, and F, and finally eliminated in runs G and H. In run H, a short run, the concentration of the raw waste was increased and the volume reduced so that the loading was approximately the same.

Table I also gives the averages of the daily removals of total solids, organic solids, and B.O.D., as well as the standard deviations and the standard error of the means. These values were used in an analysis of variance to determine significant differences between the runs. The raw waste in run G

was normal in concentration and volume and without added chemical nutrients. For these reasons it was considered as the control run for comparison purposes and the data from it were compared statistically with those from all the other runs. There were no significant differences between run G and the other runs with respect to percentage removal of total solids. However, there was a significant difference in the percentage removal of organic solids between runs E and G. There was also a significant difference in the percentage removal of B.O.D. between runs A and G. It should be remembered that run A appeared to be overloaded at the time it was in operation; this observation was confirmed by the significant difference in the B.O.D. removals. During runs A, B, C, and D the sludge did not settle as well as in the succeeding runs. Whether the reason for this was the different amounts of nitrates and phosphates added to the raw waste or the influence of the improved settling tank was not evident.

Conclusions on Waste Treatment

The following conclusions have been drawn from the results of this investigation:

1. When properly executed, activated sludge offers an excellent means of treating citrus wastes. A high-quality effluent is produced that is clear, odorless, and contains less than 10 per cent of the raw waste B.O.D. When the system is overloaded the quality of the treatment declines. The maximum loading appears to lie between 0.163 and 0.260 lb. of B.O.D. per cubic foot of aeration volume per day.

2. Additions of nitrogen and phosphorus to the raw waste appear to be unnecessary, since no significant difference in the removal of B.O.D. occurred when such additions were made. In a recent publication, McKinney, Poliakoff, and Weichlein (2) stated that while citrus waste is deficient in nitrogen, nitrifying bacteria in the sludge can fix enough nitrogen from the air to make up the deficiency. Their hypothesis, although not confirmed by any nitrogen analyses, may explain why no additional nitrogen compounds are needed.

3. The orange juice used in this work contained varying amounts of pulp, which consisted mostly of juice sacs, which in turn are composed mostly of cellulose. Cellulose is a relatively stable carbohydrate and is therefore not affected greatly during the short detention time in the aeration vessels. Hence, the reduction in total and organic (volatile) solids is not a good indicator of the efficiency of treatment of this type of waste. The B.O.D. of the waste is mostly dependent on the more readily oxidized dissolved or colloidal material and more nearly reflects changes taking place in the waste during treatment. Dissolved solids determinations might be useful, although the filtration of citrus wastes is usually very slow.

Dried Excess Sludge

It was reported by Hoover, Jasewicz, and Porges (1) that activated sludge from municipal sewage contained significant amounts of vitamin B_{12}. Two portions of the activated sludge from the foregoing treatment of citrus wastes were centrifuged from the supernatant liquid and oven dried. These samples were assayed for vitamin B_{12} by the U.S.P. XIV microbiological procedure. They were found to contain 2.3 and 2.8 μg. of the vitamin per gram of dry sludge. These values were in the same range as reported by Hoover *et al*, for commercially produced dried municipal sludge (1.6 to 4 μg. per gram). It was decided, therefore, to prepare a larger quantity of dried sludge from citrus waste for vitamin studies.

Production of Sludge

Each day 40 gal. of raw waste were prepared by diluting orange juice with tap water to 0.25 per cent total solids. This was pumped at a steady rate throughout the 24 hr. to an aeration tank holding 30 gal. The overflow from this tank was settled, the sludge being continuously returned to the aeration tank and the supernatant effluent discarded. Sufficient sludge was withdrawn each day so that the concentration remained approximately 16 per cent by volume (after centrifuging for 5 min.) To reduce the work load on the personnel, the only routine analyses carried out were pH determinations and sludge volume determinations. The excess sludge withdrawn was centrifuged in a basket-type centrifuge to reduce the volume and stored at 32° F. until the end of the run, when all of the remaining sludge was settled and centrifuged. The sludge was then dried on a small steam-heated drum drier. This run lasted for about four months.

Although a minimum of chemical analyses was made during the run, more attention was paid to the microscopic appearance of the sludge. It was found that the relative number of *Vorticellae* present was a fairly good indicator of the condition of the sludge. The presence of relatively large numbers was associated with fast settling sludge and a clear effluent. A lowered aeration rate was associated with fewer *Vorticellae*, poor settling sludge, and a cloudy effluent.

After this run had been in operation about eight weeks, it was noticed that the pH was gradually decreasing, with some lowering of the sludge quality even though the known requirements were thought to be favorable. Perhaps the previous conclusion that additional nitrogen compounds were unnecessary was premature and nitrogen deficiency was beginning to appear. The addition of 25 p.p.m. of ammonia to the raw waste raised the pH above 7 and returned the sludge to conditions of high quality. However, replacement of the ammonia by an equivalent amount of sodium hydroxide (59 p.p.m.) maintained both an average pH of 7.32 in the mixed liquor and a high quality sludge. It was concluded, therefore, that citrus wastes may be somewhat deficient in buffering power. This can be corrected easily by the addition of a small amount of alkali. Possibly the beneficial effects reported by Sanborn and Canham (6) and by Wakefield *et al.* (7) from the addition of nitrogen and phosphorus compounds were mostly due to the increased buffering capacity in their presence. All citrus canning plants use alkaline cleaning agents for scrubbing their equipment and for other purposes. If admitted to the treatment system continuously or in small increments, these spent cleaning solutions should supply the needed buffering power.

After the sludge was dried, 10 lb. of it were supplied to the University of Florida Agricultural Experiment Station. By chicken feeding tests, the details of which will be published elsewhere, it was found that the sludge contained 2.0 μg. of vitamin B_{12} per gram of dried sludge. When fed at the level of 5 per cent of the ration, no toxicity effects were noticed. No attempt was made to increase the vitamin B_{12} content by the addition of small amounts of cobalt salts to the raw waste.

Since the vitamin B_{12} content of this citrus sludge was only moderately high compared to other materials currently marketed for their content of this vitamin the sludge was analyzed for other vitamins of the B-group in order to determine if other nutritional factors are present (see Table II). The sludge was also found to contain 2.52 per cent nitrogen (Kjeldahl), which corresponds to 15.75 per cent protein. For use in chicken feeds it is believed that dried citrus sludge

should occupy a place intermediate between dried distillers solubles and dried whey. If this be true, the cost of drying and marketing the sludge should be recovered by its sale for incorporation in animal feeds.

TABLE II.—B Vitamins in Dried Citrus Sludge

Vitamin	Micrograms per Gram of Dried Sludge
Niacin	35.0
Riboflavin	9.4
Pantothenic acid	20.0
Thiamin (vitamin $B_1 \cdot HCl$)	5.0
Pyridoxine	5.0

Conclusions

On the basis of laboratory studies the activated sludge process offers a promising means of treating the waste water from citrus processing plants. Although this waste is low in nitrogenous compounds, no additional quantities need be added. It may be necessary, however, to add small amounts of alkaline materials to maintain a favorable pH. The excess sludge produced may be dried on a drum drier and used as a source of B-vitamins in animal feeds.

Acknowledgments

The authors wish to acknowledge the assistance of S. V. Ting in preparing the statistical data in this report, E. C. Hill in making the microscopic examinations of the sludge, and Mrs. Betty Murphy in making many of the analyses. The poultry feeding tests were carried out by J. Clyde Driggers.

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CANNERY WASTE DISPOSAL BY IRRIGATION *

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Constantly increasing insistance that pollution of both surface and ground waters be stopped or reduced, together with increased population in many areas, often requires a re-evaluation of pollution control procedures, including methods of waste disposal. The problem is not merely one of finding a method which will reduce or eliminate pollution, but one which will satisfactorily solve the problem at a cost within the limits which the industry can afford to pay. This would be greatly simplified in many instances if the economic problem could be forgotten, but this is seldom practical.

Even in a large city the industrial wastes load may often nearly equal that due to the domestic population plus the normal city activities. In a small city, a single industrial plant often greatly exceeds the entire community in its waste production. Not only are the industrial wastes often much stronger than the normal sewage, but the volume also may greatly exceed that of the normal sewage. If an industry operates on a year-round basis, agreement may be reached whereby the industry aids in the cost of the plant and its operation, provided, of course, that joint treatment is possible. On the other hand, where the industry operates for only a few weeks, it is seldom possible to justify the enlargement of the regular sewage treatment plant to the point where it can successfully handle the joint load. Separate pretreatment of the wastes, or completely separate disposal, may be required.

Under such conditions, disposal of industrial wastes by irrigation may prove to be economical. At various times, sewage has been disposed of by irrigation; in some instances, as at Walla Walla, Wash., a mixture of sewage and industrial wastes is used for crop irrigation. This paper is primarily concerned with the disposal of industrial wastes separate from municipal sewage, the discussion being further restricted to cannery wastes.

Previously Reported Examples

Before detailing the current work, it may be well to briefly review some of the published studies. Irrigation disposal of cannery wastes has been described by Warrick, Wisnieswski, and Sanborn (1). Wastes from peas and cream-style corn canning were discharged, unscreened, along with tank water, to a 1.88-acre irrigation field. The study was made during 1942, but the field had been in use since 1934. Some odor was reported, but less than from untreated lagoons. Rainfall during this season was in excess of normal. The wastes were discharged to the field at an average rate of 176 g.p.m. during the hours of operation and clean-up. The plant was at Hampton, Iowa.

A second plant was located at Waverly, Iowa. Here screened wastes from cream-style corn were mixed with waste from the silage stack and pumped to a 1.87-acre irrigation field. This field, consisting of loose black soil, operated successfully during the 1942

* Presented at 1954 Annual Meeting, Pacific Northwest Sewage and Industrial Wastes Assn.; Eugene, Ore.; Oct. 21–23, 1954.

corn pack. No other wastes were applied during the year. Rainfall was above normal; odors were noticeable only within, or at the edge of, the field. Wastes were applied at an average rate of 123 g.p.m. during the working hours.

No complaints were reported from either of the foregoing fields during 1943.

Webster (2) indicates that crop irrigation began at Bridgeton, N. J., in 1900, when 3 acres of land were under overhead irrigation. By 1953 about 200 acres of overhead irrigation were in use, and had been for more than 30 years. In addition, 3,500 acres are now being watered by portable-type irrigation. In the earlier years, stream and pond water was used, but now vegetable processing water is used except at installations too remote to have access to such wastes.

Liquid wastes from vegetable processing amount to about 10 m.g.d. By 1944 this had become such a serious problem that the New Jersey State Department of Health ordered installation of equipment to abate pollution. Pilot-plant studies in 1949 indicated that a high-rate trickling filter would be the best method, at a cost of $1,750,000. The only alternate method that had not been considered was spray irrigation, so tests were made on a plot of sandy loam adjacent to a wooded area. The plot had a good stand of crimson clover. After 2 in. of water had been applied, puddling and runoff were encountered in this field, but not in the wooded area, where a portion of the spray had fallen because of bad adjustment of the spray nozzle. The nozzle was then relocated in the woods and the ground absorbed more than 100 in. of water continuously applied. This, then, was the solution. The cost of complete installation was only $150,000.

Of 200 acres of wooded area, 84 were under spray irrigation. Each acre received an application of water for 8 hr., then was allowed to rest for 24 hr. The amount of water applied per acre varied from 0 to more than 1,200 in. per year.

By the end of each season, the wooded areas showed a lush growth, particularly of weeds and grasses. There was no evidence of soil clogging. Pooling and runoff were practically nil. The quantity of ground water was checked closely in some 40 test wells. The water table rose and fell in direct relation to the quantity of water applied to the surface. Chemical and biological tests were made on the ground water from three of the test wells in 1950, and more since that time. The waste water was purified to practically potable quality in the first 3 in. of soil (Sassafras loamy sand).

Webster (2) made no attempt to compare the results of using fresh or surface water with waste water on crop yields, but pointed out, however, that adding much-needed water to plants will make a vast difference in yield. Neither did he assess what effect the waste water has on soil fertility, although here, again, it is obvious that the plants get some benefit from the nitrogen compounds in waste water.

Sanborn (3) states that in 1947, the Hanover Canning Co., at Hanover, Pa., faced the problem of preventing overflow from a lagoon from entering a small stream. Spray irrigation was used, and this seems to have been the first time this method was tried for waste disposal. Lakeside Packing Co. in Minnesota, and Seabrook Farms in New Jersey, began using the method in 1950, and in 1951, a total of 22 plants were using spray irrigation. Two dairy plants were also using spray irrigation.

In describing the Lakeside installation, Nelson (4) describes the system in detail. A 110-acre farm was divided into six fields of about 18 acres each with a 6-year rotation of sweet corn, canning peas, and four years of alfalfa-

brome hay. In any one year there would be 72 acres of hay.

In 1951 the company packed 244,000 cases of peas and 122,000 cases of corn, and discharged 23.8 m.g. of waste (approximately 65 gal. per case). As there was sufficient rain this season for crop production, the disposal schedule was adjusted to interfere the least with farming operations, hence the hay got most of the water.

The intent was to move the sprinkler lines twice a day. But once a line was left in alfalfa for three days; in which case the acre received 17.8 in. of water during that time, or approximately 6 in. per day. Many of the alfalfa leaves dropped off, but no permanent damage developed.

Monson (5) has given some data on several of Green Giant Company's installations. The first installation was at Watertown, Minn., where a 10-acre plot took care of 15 to 18 m.g. of waste per season, or an average of 500,000 g.p.d., exclusive of cooling water. The plot was divided into five fields of 1.25 to 3.5 acres. A ridge-and-furrow system was used, which required construction of main ditches along the land contours. This system has been in satisfactory operation for six seasons. At the start it was thought that two men would be required to operate the system, but it was soon found that one man could do the job. The odor problem has been practically nonexistent.

At Blue Earth, Minn., spray irrigation has been used to handle from 600,000 to 700,000 g.p.d. Originally a ridge-and-furrow system was installed. At the end of the first (1950) season, it was found that labor requirements were high and that water quantities were too great to be properly controlled on steep areas (exceeding 10 per cent in some spots). In 1951, spray irrigation was used on 24 acres of bluegrass and woods. Sprinklers were left in one location for from 8 to 12 hr., with an application of from 4 to 6 in., equivalent to 0.5 in. per hr. Some areas became soft, but recovered in 10 to 12 hr. Cattle were pastured continuously without damaging the turf. Although this area had slopes up to 8 per cent, there was no runoff. A similar experience took place at Montgomery, Minn.

Several conclusions were reached from these experiences. The cost of ridge-and-furrow irrigation, including cost of the land, depreciation, operation, and maintenance was about $0.01 per case. Costs with spray irrigation were somewhat higher. Originally, efforts were concentrated on the problem of waste disposal, but use of land for cattle pasturage has been started, and this will reduce the cost somewhat.

The vegetative cover was very important, and it was recommended that the field be prepared and planted two years in advance of its use for waste disposal. Soil tests should be made to determine the best types of grasses to be grown. To avoid odor problems, retention time should be kept low, as a large reservoir permits wastes to become septic and odorous. In one plant the capacity of the reservoir was sufficient to hold only 30 min. storage. Odor was not a problem.

Breysse (6) has given some data on spray irrigation at Pomeroy and Waitsburg, Wash., where pea canneries are located.

The Green Giant Cannery at Pomeroy operated for 28 days in 1953, during which time it discharged approximately 1 m.g.d. of wastes. Under the present arrangement the farmer using the wastes receives payment from the cannery, based on the number of cases packed. The wastes from the cannery flowed by gravity to three storage ponds on a farm located about ¼ mi. from the cannery. The ponds also received effluent from the local sewage plant, which averaged about 175,000 g.p.d. From the ponds the wastes were pumped to the fields, so that the ponds served primarily as equalizing sumps.

Of the 60 acres of pasture land irrigated, 40 acres were planted to al-

falfa and 20 acres to grass. Alfalfa was sprayed for 12 hr., the grass for 24 hr. at a time. Experience indicated that if alfalfa was sprayed for more than 12 hr., it would burn up, although the root system was not destroyed, and the crop would be back the following year. This system has operated successfully for several years, with no odor problem except occasionally at the ponds. This seems to happen only when the pumps get behind, and wastes are thus stored for a number of hours.

The other plant is located at Waitsburg, where the wastes must be kept separate from the sewage. Prior to 1953 the cannery wastes were discharged into the Touchet River, creating pollution and nuisance conditions. In 1953, spray irrigation was tried.

The cannery owned 24 acres of land adjacent to the plant. Bordering this plot was an apple orchard which had been irrigated in previous years with well water. The cannery agreed to let the owner use all the effluent he desired, provided he would supply his own pipe and help move the cannery laterals.

The plant effluent was not measured, but the incoming water to the plant amounted to about 1.5 m.g.d., of which approximately 75 per cent was discharged as wastes to a sump for pumping into a 6-in. main. Laterals were both 4 and 6 in. in size, and Rain Bird nozzles were used.

The existing pasture cover was utilized. At first the laterals were moved after puddling began, but this produced odors. The laterals were then moved every day, which remedied the odor problem.

During the 1954 season, spray irrigation on the pasture was continued. At the end of the season very little grass was alive, and there was evidence of ponding.

Sanborn (3) indicates that on relatively level land with a good cover crop it is common practice to apply from 3 to 4 in. of waste at a rate of 0.4 to 0.6 in. per hr.

Although this paper is not concerned with sewage disposal, it may be worth noting a report by Henry, *et al.* (7) giving results of a study made in Wisconsin. The paper showed that (a) 40 in. or more of sewage effluent can be applied to a crop of Reed canary grass during the growing season, weather conditions being normal, but it is likely that less effluent could be applied to crops that grow over a shorter period or are not as tolerant to wet soil conditions; (b) the crop and soil are effective in removing virtually all of the nitrogen, phosphorus, and potassium from the percolating waters, although a high concentration of sodium in the effluent will increase the losses of calcium and magnesium to the percolate, perhaps resulting in damage to the physical condition of the soil if sodium continues to accumulate in the soil; (c) crop yields were substantially increased by plant nutrients in the effluent, the increases amounting to about 1 ton per acre on Miami silt loam (a mineral soil) and about 2 tons per acre on peat (a soil high in organic matter); and (d) drainage waters from the soil irrigated with sewage effluent did not increase the coliform index of the nearby creek, although the chloride and, to a lesser extent, the sodium content of the creek waters was increased. It must be recognized, of course, that some of these conclusions may not apply to a particular industrial waste.

The possible contamination of ground water must be considered (8).

It appears that spray irrigation is quite simple, but it is found to have limitations. This system of disposal depends largely upon absorption into the soil, hence there must be available suitable land areas within a reasonable distance from the plant.

Bare land will take little water before flooding occurs. It was first thought that the method would be suitable only in regions where the soils

had unusually good water absorbing characteristics, but this has been shown to be untrue if an adequate cover crop is present. Although an inert cover of straw will work, growing plants are preferable because infiltration is increased by virtue of the root system and some moisture absorbed into the ground is transpired into the air. The choice of cover crop will depend on climatic and soil factors. Such crops as peas and beans are not desirable, as there is a definite limit to the amount of water which they tolerate. Nevertheless they can be used provided sufficient area is available.

Spray irrigation as described is a waste disposal method, and should be so considered; hence, it is not likely to return any profit. It attempts to discharge a large quantity of waste on as small an area as possible without regard to the crop requirements, except to avoid killing the vegetation. However, some return from hay or use of land as pasture is usually possible.

It should be obvious from the foregoing that irrigation disposal of sewage and industrial wastes involves two rather different concepts. One treats it solely as a waste disposal system, in which the intent is to get rid of as much liquid as possible on as small an area as possible, any crop production being incidental to the process. Here the nature of the crop is of prime importance, as some plants will tolerate considerably more water than others. The other concept considers the liquid as of definite value as a supplement to other sources of water to be used for crop irrigation. Land requirements will be higher. Some of the installations mentioned have actually utilized both concepts in varying degrees.

Dayton Experiment—1954

The situation at Dayton, Wash., where the Green Giant Company has a plant which cans asparagus and peas, is similar to many others. The process wastes are greatly in excess of the normal sewage, both in volume and in strength, hence the sewage treatment plant, which now receives about 74 per cent of the plant effluent, is grossly overloaded, particularly during the pea canning season. The situation has been under study, and during the past summer, some experiments were undertaken looking toward the possible disposal of the wastes by irrigation.

Test plots were located in two different areas, separated by a roadway. One was in alfalfa, the other in pasture grass. Because of the practical problems involved in hauling the wastes from the cannery, the test areas were only 3 ft. by 3 ft., and the wastes were applied by the use of ordinary garden sprinkling cans. Sprinkling was done every 15 min., and the total application over an 8-hr. period being 4 in., or 0.5 in. per hr.

In each field there were selected six plots 3 ft. by 3 ft. in size, three of which were irrigated with straight blancher waste, while the other three were irrigated with effluent from the plant. In the alfalfa field an extra plot was selected as a control unit, the soil being made barren of all vegetation, so that the actual soil absorption capacity could be measured. The plots were lettered as follows: Plot A was watered every day; Plot B was watered every other day; and Plot C was watered only on every fourth day. This procedure was established with the purpose of determining the maximum hydraulic and B.O.D. loading that could be applied to the plots without causing severe detrimental effects to the foliage.

Due to the practical problem involved in getting the wastes from the plant to the field, it was decided that two daily trips would be made. This resulted in a minimum detention time of 4 hr. prior to application. The resulting effect of the souring (lowered pH) of the wastes due to prolonged periods of detention was not studied during this experiment. It should be noted that blancher waste is too hot to be applied, and had to be

TABLE I.—Condition of Foliage Under Irrigation with Blancher Waste (Alfalfa Field) and Plant Effluent (Grass Field)

Date	Blancher Waste			Plant Effluent			
	Plot A	Plot B	Plot C	Plot A	Plot B	Plot C	Control[1]
June 25	Good	Good	Good	Good	Good	Good	100%
July 8	Pale green	Good	Good	Good	Good	Good	100%
9	Pale green	Good	Good	Good	Good	Good	90%
11	Straw green	Good	Good	Good	Good	Good	90%
12	Straw green	Pale green	Good	Good	Good	Good	90%
13	Straw yel.	Pale green	Good	Good	Good	Good	75%
14	Straw yel.	Straw green	Good	Straw green	Good	Good	75%
15	Yellow	Straw green	Pale green	Straw green	Good	Good	75%
16	Yellow	Straw yel.	Pale green	Straw green	Good	Good	75%
17	Yellow	Straw yel.	Pale green	Straw green	Good	Good	75%
18	Wilting	Yellow	Straw green	Straw green	Good	Good	75%
19	Wilting	Yellow	Straw green	Straw green	Good	Good	65%
20	Wilting	Wilting	Straw yel.	Straw yel.	Good	Good	65%
21	Wilting	Wilting	Straw yel.	Straw yel.	Straw green	Good	65%
22	Dead	Wilting	Yellow	Straw yel.	Straw green	Good	65%
23	—[2]	Dead[2]	Yellow	Straw yel.	Straw green	Good	60%
24	—	—	Wilting	Straw yel.	Straw green	Good	60%
26	—	—	Wilting	Yellow	Straw yel.	Good	60%
27	—	—	Dead	Wilted	Straw yel.	Good	50%

[1] Bare soil, therefore soil infiltration rate.
[2] Discontinued.

allowed to cool several hours before being applied.

The field that contained permanent pasture was being grazed by cattle during the experiment. During the first few days after application had begun, the cattle ate the grass and stomped the surface of the ground to the extent that new, fenced plots had to be selected. Table I summarizes the results.

Blancher Waste Application on Alfalfa

The blancher waste applied in this experiment had an average 5-day B.O.D. of 30,000 p.p.m.

Plot A

After 8 days of application of blancher waste to Plot A, the color of the foliage turned from a bright green to a pale green. On the 15th day the color had turned yellow, and by the 23rd day the foliage had all wilted and had taken on a sun bleached, burnt appearance, at which time this plot was discontinued.

Plot B

After 12 days of application of blancher waste to Plot B (every other day application) the color of the foliage had also turned from a bright green to a pale green. On the 18th day the color had turned yellow and on the 23rd day of application the watering of this plot was also stopped.

Plot C

After 15 days of application of blancher waste to Plot C (every fourth day application) the color of the foliage had turned from a bright green to a pale green. On the 22nd day of application the foliage had turned yellow, and on the 27th day it had wilted and was dying.

Plant Effluent Application on Alfalfa

The waste that is called plant effluent is composed of all discharged wa-

ters from the plant excepting the cooling water. The plant effluent had an average B.O.D. of 1,200 p.p.m.

Plot A

After 14 days of application of plant effluent to Plot A (daily application) the color of the foliage had turned from a bright green to a pale green. On the 20th day of application the color was straw yellow and on the 27th day the foliage had wilted and seemed to be dying.

Plot B

After 21 days of application of plant effluent to Plot B (every other day application) the color of the foliage had turned from a bright green to a pale green. On the last day of application the foliage was turning a straw yellow color.

Plot C

Plot C, which was watered every fourth day with plant effluent, grew a better-than-normal cover drop and no adverse conditions could be detected.

Application on Permanent Pasture

The use of blancher waste for application on the permanent pasture gave results comparable to those obtained in the alfalfa field except that Plot C had some very few scattered plants still alive at the end of the experiment.

The use of plant effluent on the permanent pasture showed that the grass was less susceptible to the organic loadings than was the alfalfa.

Control Plot

The control plot was watered daily with plant effluent. After 9 days of application only 90 per cent of applied water was percolated. On the 13th day the plot would only take 75 per cent of the amount applied; on the 19th day, only 65 per cent. At the termination of the experiment, the plot would take only 50 per cent of the original 4 in. per day applied.

Summary

At the close of the experiment it was decided to leave the plots intact and determine if the vegetation would recover. After 30 days, an inspection was made of all plots. The plots irrigated with blancher waste had not recovered. The plots irrigated with the plant effluent recovered as follows: Plot A, 50 per cent; Plots B and C, 100 per cent of normal coverage.

From the foregoing data it appears that the organic loading of the blancher waste caused the killing effect on the plants. The effect was similar to that of an over-application of fertilizer. This seemed to be true even on Plot C.

On the plots irrigated with plant effluent the hydraulic loading seemed to be the controlling factor. This conclusion seems justified in that Plot B fully recovered after effluent application had ceased.

The application of undiluted blancher waste to these two types of plants is impractical, due to the fact that the foliage would be permanently killed unless only one or two applications were made.

An every fourth day application of plant effluent could be used and a full use made of the cover crop. Table II indicates the land requirements. However, the application of plant effluent could be used at the rate of 4 in. per day on an every other day schedule if the cover crop was not utilized.

TABLE II.—Dayton, Wash., Irrigation Study Data

Application rate (a.-in./day)	4
Application rate (m.g.a.d.)	0.1088
Water used,[1] max. (m.g.d.)	1.929
Process waste,[2] volume (%)	73.7
Process waste, volume (m.g.d.)	1.422
Irrig. area needed[3] (acres)	13

[1] July 29, 1951, Dayton plant data.

[2] Table III, p. 17a, "A Study of Waste Sources, Volumes, and Quality from the Pea Cannery of the Green Giant Co., Dayton, Wash., 1952." San. Eng. Sect., Div. of Indus. Research, Washington State Inst. of Tech.

[3] For 1-day cycle; for each additional day in the cycle, a like area must be added.

The control plot points up the interesting fact that of two identical soils, the soil covered with vegetation will utilize the most water.

The data also point up the interesting fact that the permanent pasture grasses were apparently able to take a heavier organic loading than alfalfa under identical conditions.

These studies were not sufficiently extensive to indicate to what extent the limiting application was due to excess quantity of water or to organic loading.

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NATIONAL REGISTER OF SANITARY ENGINEERS

Sanitary Engineers throughout the country will soon be contacted by the U. S. Public Health Service in the development of a National Register of Sanitary Engineers. The register is being developed at the request of the Office of Defense Mobilization and the activity has been integrated into the over-all program of the National Science Foundation.

In 1949, the American Public Health Association prepared a National Roster of Sanitary Engineers for the National Security Resources Board. Maintenance of that roster was discontinued a few years ago. The proposed register is being prepared to have available complete information on trained technical and scientific personnel who might be needed in case of enemy attack or other major national disaster. All the professional organizations in the United States with which sanitary engineers are affiliated are cooperating.

A major mailing list of over 10,000 names of sanitary engineers has been developed. A one page information sheet which requires only a few minutes to fill in has been prepared in cooperation with the Engineers Joint Council and the National Science Foundation and will be sent during the next several months to each engineer whose name is on this list. A letter of explanation will accompany the information sheet. Each recipient will be asked to read the accompanying National Research Council's definition of a sanitary engineer (see THIS JOURNAL **27**, 5, 586; May, 1955) before transmitting his reply.

By this means, details on the engineer's education, his professional experience and his sanitary engineering specialty will be recorded. When completed, the register will be maintained by the U. S. Public Health Service.

Stream Pollution

PLANKTON AND INDUSTRIAL POLLUTION IN CLEVELAND HARBOR *

By Charles C. Davis

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Between September 1950 and September 1951 a study was made of the Cleveland Harbor area in connection with a survey of pollution conditions in Lake Erie. Based on this study, previous reports have been published on the chemical and physical results (17)(20), on the analyses of the phytoplankton (18), and on the analyses of the zooplankton and the seasonal ecology of the entire plankton (19).

Two inter-connected aspects of the study of the plankton in relation to pollution are: (a) the effect of pollutants on the plankton, and (b) the use of the plankton organisms as indicators of polluted waters. These two aspects stand to each other as the two sides of a coin.

Effect of Pollutants on Plankton

There is considerable of interest in the study of the direct effect of pollution upon the plankton organisms, for the phytoplankters lie at the very base of, and the zooplankters are the most important and abundant intermediaries in, the complex aquatic food chain that leads ultimately to the larger fish and to man. If phytoplankton production is either reduced or increased through the effect of industrial or domestic sewage effluents, or if there are similar effects upon the zooplankton, then the fishery and man's economic welfare may either deteriorate or be augmented, as the case may be.

The effect of domestic sewage effluents is largely associated with the organic putrescible nature of the wastes. Unless adequately pretreated in suitable disposal plants or septic tanks, domestic effluents undergo further decay after entering natural waters. Especially in small streams at low-water stages, or in ponds or small lakes, the oxidative processes associated with the decay often result in a serious depletion of the dissolved oxygen content of the water, to the point where fish or fish-food organisms are either asphyxiated or they seek more pleasant surroundings. At times, after depletion of the oxygen, anaerobic decay continues, with production of hydrogen sulfide, an extremely toxic gas capable of transforming a formerly productive pond or lake into a biological desert. Many examples are cited in the literature of dangerous or lethal reduction of oxygen by domestic sewage pollution (27)(64)(21).

Conversely, however, organic pollution may increase the fertility of natural waters through the addition of such plant nutrients as phosphates and nitrates, and lead to increased productivity of the phytoplankton and of other plant life. This would lead subsequently to an increase of animal

* Part IV of "A Preliminary Study of Industrial Pollution in the Cleveland Harbor Area, Ohio" (see references 20, 18 and 19 for Parts I, II and III).

life, including fish life. In recent years there has been a considerable amount of experimentation in the artificial fertilization of ponds and small lakes. Results of the experiments, although usually leading to increased productivity, have not been uniformly satisfactory from the point of view of fish production. Smith and Swingle (52), for example, artificially fertilized a number of small ponds, and reported in every case an increased production of phytoplankton, and a doubling of the production of bluegill bream, as compared to unfertilized control ponds. On the other hand, Ball (4) described detrimental effects resulting from the fertilization of natural lakes in Michigan. The fertilizing effect of domestic sewage effluents in nature has been observed and described frequently in rivers, lakes and in the sea (49)(50)(38)(53). Minder (41)(33) pointed out that sewage effluents, even though they increase the fertility, may lead to a deterioration of the flavor of fish, and to the replacement of desirable species of fish by coarser varieties.

Many types of industrial pollution, especially from the food industries, exert an effect similar to domestic sewage, although often of a much more severe character. In San Diego Bay, Calif., a severe drop was observed (8) in the oxygen content of the water in the vicinity of the greatest industrial pollution (largely from the fish-canning industry). Southgate *et al* (54) have described the untoward effects of organic industrial pollution in British rivers and streams, and many similar cases can be gleaned from the extensive literature both in the United States and elsewhere.

Apart from putrescible organic effluents, however, industrial effluents often contain materials, organic or inorganic, that are directly toxic to plants and animals living in lakes and streams into which they are disposed. Among these toxic substances are the phenols, many of the metal ions, the cyanides and the chromates. Some cases of this type resulting from effluents of the metal-plating industry have been described by Oeming (43). In Germany, Thienemann (59) cited 120 cases of fish mortality, of which 62 were the result primarily of industrial pollution, and 25 of combined industrial and domestic sewage. He also (60) described the general effects of industrial pollution in Sweden.

More specifically, Doudoroff *et al.* (22)(23)(24) have reviewed not only bioassay methods for the detection of the toxicity of industrial wastes to fish, but also the literature concerning the toxicity of industrial wastes to fish. The effects upon planktonic animals (*Daphnia* mainly) of specific substances to be found in industrial effluents have been studied (1)(2)(5)(34). The effects of such toxic industrial pollutants in nature have often been described, among the most striking cases being those discussed by Turing (61) and Baldi (3).

Plankton as Pollution Indicators

Studies in recent years have shown that unpolluted natural waters contain a wide variety of organisms, none of which usually occurs in overwhelming numbers. Organic pollution (domestic or industrial) results in the elimination of the less resistant forms, but those species that are better able to withstand the conditions of low oxygen, high turbidity, etc., that are associated with the pollution are able to increase to enormous numbers because of the rich food supply and the relative lack of other competing species. Pollution by metal ions and other poisons, however, may have very different effects. Southgate *et al* (54) showed that effluents containing copper and chromium were toxic to all river animals, and where pollution was highest the river was devoid of all animal life. Although some species were less susceptible than others to

these pollutants, and in regions of less pollution some animals persisted where others were absent, all animals were adversely affected.

The discovery of such effects of pollutants upon organisms has led to attempts to find species or groups of organisms that can be used as convenient indicators of pollution, and of the degree of pollution. These attempts have been rather successful for bottom-living organisms. Biological measures for the assay of stream conditions, for example, have been suggested by Patrick (48), using benthic species. Similarly, bottom organisms are useful as indicators of organic pollution in lakes (56).

The collection and analysis of odoriferous bottom samples from highly polluted waters is not a task that has overwhelmingly appealed to aquatic biologists, and therefore the possibility of using planktonic organisms as indicators has been explored. Quantitative samples of the plankton are as easily obtained as samples of the water itself, and analysis, though complex, does not involve the sorting out of organisms from obnoxious sewage sludges. The effects are as marked upon suspended organisms, of course, as upon those on the bottom.

A number of studies have been conducted on the effects of pollution upon the plankton of streams and rivers, and the use of planktonic species as indicators of stream pollution has been investigated. As previously suggested, the effects often are obvious, and in certain special circumstances planktonic organisms have proven to be suitable indicators, as for example the presence of *Euglena mutabilis* in waters contaminated with acid (13)(36). Whipple (65) listed a number of planktonic indicators of pollution, but other investigators, such as Lackey (37), disagree with his list and point out the necessity of gathering further data on tolerances of specific organisms before any accurate and all-inclusive list can be drawn up. Most recent investigators of river and stream pollution agree with Roach (51), who summarized his results as follows: "The quality of the plankton found at the polluted stations does not differ from that found in clean water. . . . Quantitatively plankton abundance is controlled by such a variety of factors that little importance can be attached to the numerical data. Therefore plankton cannot be of much value as criteria pollution."

Except in special circumstances the plankton is less suitable than bottom forms as an indication of stream pollution for several reasons. Among these are: (a) the suspended plankton population is subjected only to the environmental circumstances prevailing in its immediate water mass, whereas bottom forms are subjected to the various water masses that pass over them, and therefore can better reflect intermittent pollution; and (b) unless the effluent contains extremely toxic products, the effects of pollution upon the organisms appear only after a greater or lesser period of time subsequent to contact with the polluting effluent. Plankton organisms being at the mercy of the currents, these effects then might not occur until far downstream from the most highly polluted regions.

Conditions in lakes differ radically from those in rivers and streams in two major ways as to pollution effects. Firstly, the current systems of lakes are totally different from those of flowing waters, and do not carry pollutants away from the source of pollution as rapidly. Secondly the diluting capacity of the lake is many times as great as that of the stream. It is usually assumed that the pollution indicators, such as listed by Whipple (65) and Taylor (57), are to be found in lakes as well as in other waters.

The relatively small amount of information on the effect of pollution upon plankton in lakes, and the negligible information along this line for

very large lakes, made it desirable to investigate the plankton in relation to pollution in the highly polluted water of Lake Erie in the Cleveland Harbor area.

Collections and Methods

Collecting trips were undertaken in the Cleveland Harbor area approximately every two weeks from mid-September 1950 to the end of September 1951. Weather permitting, nine stations (Figure 1) were occupied on each trip. Station 1 lay a short distance within the mouth of the Cuyahoga River, and thus was in the most highly polluted water. Most of the industrial effluents of Cleveland and its suburbs are dumped into the Cuyahoga River, minor quantities flowing more directly into the lake, or being cared for by Cleveland's sewage treatment plants. The Cuyahoga also carries the treated domestic sewage effluent from the Southerly (Cleveland) sewage treatment plant, and in addition carries the major portion of the raw, untreated domestic sewage from the factories, commercial buildings, and dwellings in the highly industrialized valley of the Cuyahoga. Station 2 lay at the opening of the jetties opposite the mouth of the Cuyahoga River. The water in this location was subject to variable degrees of pollution, depending upon wind direction, wind strength, etc. Station 3 lay in relatively clean water mid-way between the opening in the jetties and intake crib No. 3 of the Cleveland water supply. Station 4 lay at the intake crib, 6 km. from shore, in water that can be considered essentially unpolluted. Stations 5, 6, and 7 lay in Cleveland Harbor proper, inside the breakwater. Station 5 was subject to heavy but variable pollution because of its proximity to the mouth of the Cuyahoga River. Station 6 was located at the foot of East 40th Street, and was less highly affected by industrial and domestic wastes. Station 7 was at the end of the breakwater, and was affected both by polluted water from the harbor and by the relatively clean water from the open lake. Stations 8 and 9 were, respectively, opposite stations 6 and 5, but outside the breakwater in the open lake, and hence reflected inshore lake conditions, modified by greater or lesser degrees of pollution.

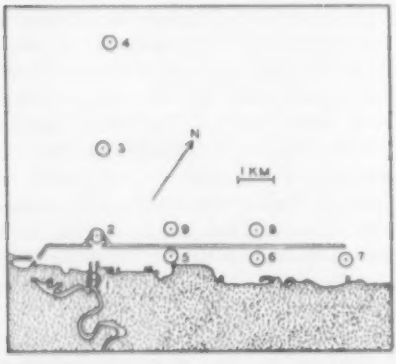

FIGURE 1.—Location of sampling stations for plankton survey of Cleveland Harbor area, Lake Erie.

Two surface plankton samples and two at a depth of 6.5 m. (approximately 1 m. above the bottom at all except stations 3 and 4, where the water was deeper) were collected at each station that could be visited on each trip. One sample at each depth was taken with a Juday plankton trap of 10-l. capacity, and one at each depth was a 250-ml. sample of raw water, preserved with formalin and subsequently centrifuged in the laboratory to occupy a volume of 10 ml. High turbidities and the importance, especially in the late summer and fall, of species of blue-green algae with a specific gravity less than that of the lake water made the centrifuged samples unsatisfactory, and they were used for analysis only in those cases where mechanical failure of the trap, or loss of the samples, caused gaps in the series of trap samples. However, all of the samples, taken on September 15 and November 11, 1950, and on

April 28 and September 3, 1951, were analyzed by the centrifuge method.

Each sample was analyzed from a 1-ml. aliquot in a Sedgwick-Rafter plankton counting cell. First counts were made of the most common organisms with the aid of an ocular micrometer, the number of fields counted depending upon the abundance of the kinds of organisms present. Somewhat less common organisms were counted by the examination of the entire aliquot. Larger forms, especially the planktonic *Crustacea*, were counted by scanning the entire sample with the intermediate power of a dissecting microscope. Appropriate calculations were made to determine the number of each organism per liter or per cubic meter.

In the case of most of the species of the phytoplankton, not only the number of individuals was estimated, but also the number of cells in those species where the colony or coenobium consisted regularly of several cells. In filamentous forms, where possible breakage of the long chains of cells during collection and handling of the samples made it impossible to determine accurately the number of individuals, only the number of cells was estimated. A differential count was kept of those cells which were dead or obviously moribund and those that appeared to be healthy. In addition, the volumes of the more important phytoplankton species were calculated, and in this manner it became possible to compare not only the numbers of the cells of individual species at the several stations, but also the total phytoplankton volumes and the relative volumes of the individual species. Volumes are expressed in cubic microns per liter.

Results

Although the results of the phytoplankton and zooplankton analyses upon which this report is based have been summarized previously (18)(19), the possible effects of industrial pollution were largely ignored. For the most part conclusions were based upon averages of the numbers or of the volumes obtained at all except station 1, with the result that the important phenomena that could be detected were (a) the seasonal distribution of the plankton as a whole and of the individual species, and (b) the effect of general environmental factors, such as temperature and food supply. It is proposed here to examine the horizontal distribution of the plankton, and thus to ascertain any effect of pollutional (or other localized) factors upon its quantity, upon the kinds of organisms present, and upon the condition of the plankton.

All of the far too few studies of pollution in Lake Erie have been more or less limited, either by artificial political boundaries or by the restricted nature of the problems that were investigated. The most extensive studies (46)(47)(39)(26)(42) have dealt only with the western or eastern basins of the lake. Similar studies undertaken at the same time in the central basin have not yet been published.

In the western basin, Wright and Tidd (66) summarized their study of pollution in relation to the decline of Lake Erie fisheries. Recently, the Ohio Division of Water (44)(45) reported on several aspects of Lake Erie pollution. Sources of Lake Erie pollution have been discussed by the U. S. Public Health Service (62).

In none of the previous studies of the plankton of Lake Erie in relation to pollution (63)(46)(47)(6)(7)(28)(29)(30)(66)(40) have the data warranted a thorough analysis of the problems involved.

Plankton Quantity and Pollution Source

Because many industrial effluents, as well as heavy organic pollution, cause the death of organisms, it was thought

that the degree of pollution might be indicated by the total quantity of the plankton. Therefore comparisons were made of plankton volumes and numbers at the several stations in relation to the pollution load, as indicated by the quantity of iron (17)(20).

The total volume of the phytoplankton was invariably lower at the surface at station 1 than at any other location. This was the most highly polluted water investigated. Deep samples at station 1 also regularly contained lower quantities than elsewhere, but occasional intrusions of lake water into this river location brought the volumes up (18)(19). Similarly, stations 2 and 5, at the times when the water at these places was highly polluted, showed low volumes of phytoplankton. Figures 2, 3, 4 and 5 show the horizontal distribution of the phytoplankton at the surface and at a depth of 6.5 meters on representative dates, compared with the iron content of the water. Low plankton volumes are clearly associated with all cases of high iron content. On the other hand, low plankton volumes also occurred at other places, where pollution was low (Figure 2, stations 4 and 9; Figure 3, stations 4 and 7; Figure 4, station 7).

Furthermore, it frequently has been shown that rivers have a much lower plankton productivity than do lakes. Recently Sullivan compared the standing crop of phytoplankton in 10 Ohio streams tributary to Lake Erie with the crop in adjoining portions of the lake itself, and invariably found smaller phytoplankton volumes in the stream waters. He concluded that most of the phytoplankters he did observe had entered the streams with an influx of water from the lake. In the present study, the water containing the largest quantities of iron and most heavily fouled with industrial and domestic effluents was the Cuyahoga River water, and probably the low phytoplankton and zooplankton volumes were a reflection of river conditions rather than of pollution conditions.

Therefore, it is concluded that in the Cleveland Harbor area, and in similar locations elsewhere, the volume of the plankton is not a reliable index of degree of pollution. It would appear that plankton volume, except in cases of severe toxic pollution, would

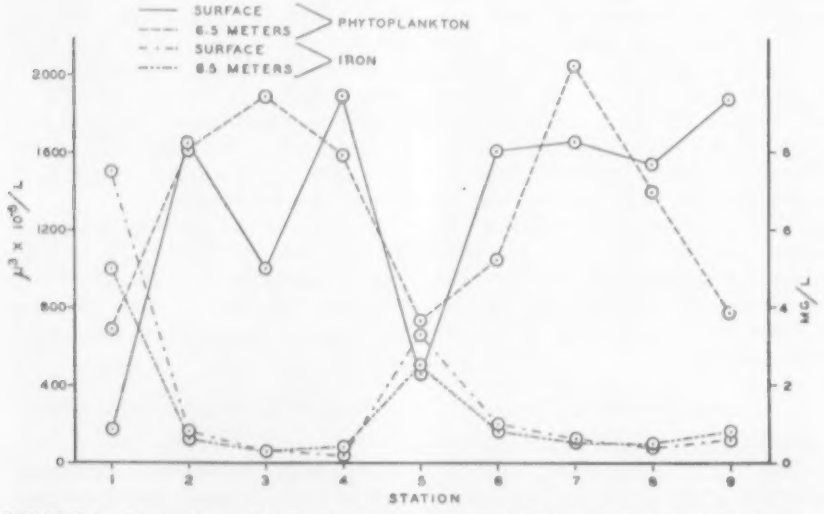

FIGURE 2.—Comparison of phytoplankton volume and total iron content, April 28, 1951.

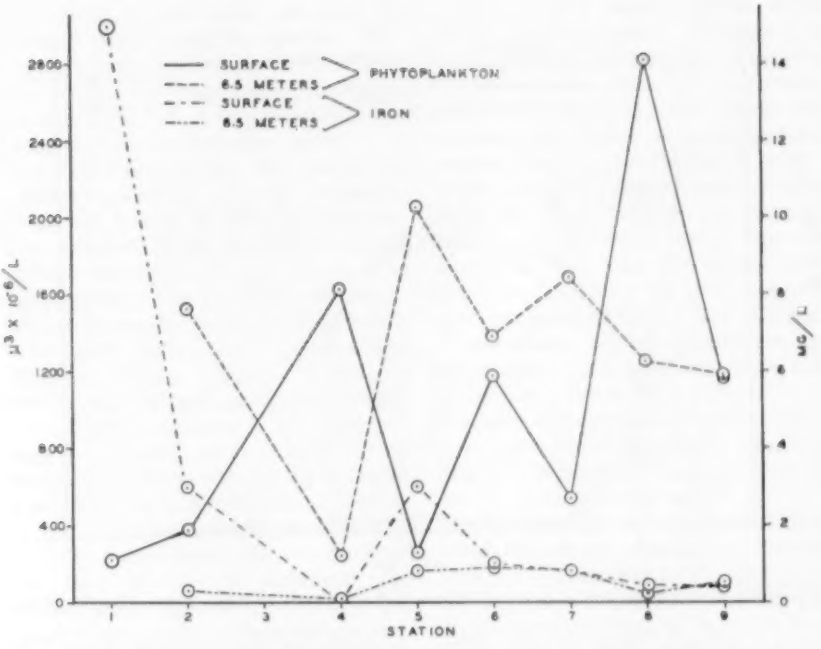

FIGURE 3.—Comparison of phytoplankton and total iron content, May 26, 1951.

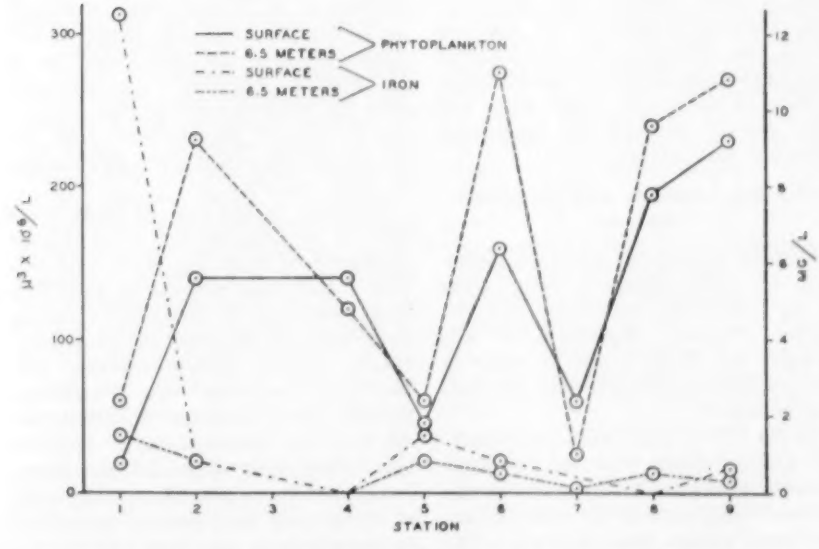

FIGURE 4.—Comparison of phytoplankton and total iron content, July 21, 1951.

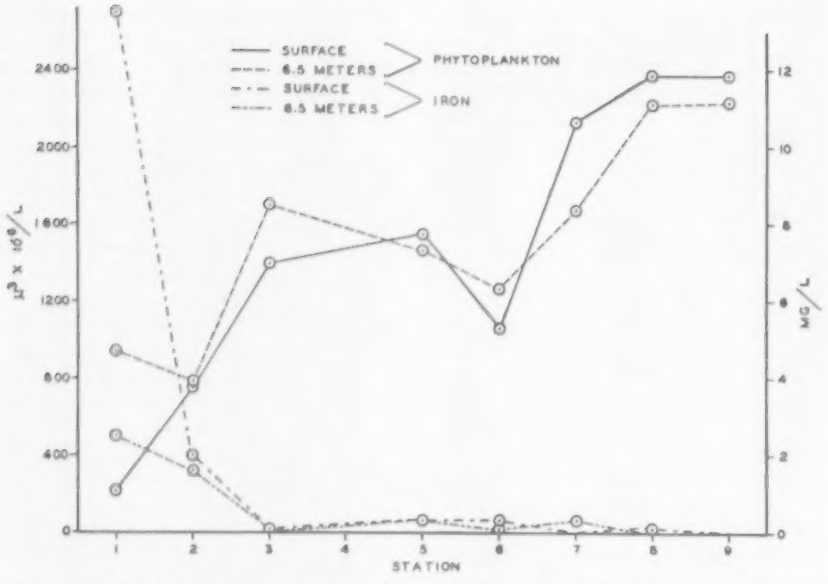

FIGURE 5.—Comparison of phytoplankton and total iron content, September 30, 1951.

not be a suitable index in large lakes, inasmuch as such large bodies of water are locally subject to great variations of plankton quantity because of the existence of many distinct water masses, each with its own characteristic plankton content. As currents carry the several water masses past any particular location, the plankton content of the water at that place will vary greatly, without any pollutional influence whatsoever.

Plankton Species and Pollution Source

Certain species of plankton organisms are more resistant than others to the effects of industrial and domestic effluents; therefore, it was thought that there might be value in the qualitative comparison of the samples obtained.

In the case of most individual plankton species, there was only a small quantity at station 1 (especially at the surface) compared to the quantity encountered at the other stations. The reduction, however, was usually proportional to the reduction of the total quantity of the plankton at this location. Similarly, Sullivan (55) observed a reduction of the quantities of most phytoplankton species in the mouths of 10 Ohio streams tributary to Lake Erie, but the decrease was proportional to the total reduction in the mouths. Sullivan's interpretation that the reduction was caused by simple dilution of plankton-rich lake water by plankton-poor river water seems to have validity.

However, in the present study there were a few species that were absent or nearly so from the surface at station 1 that were present in relatively large numbers in the lake. Among these were the phytoplankters *Botryococcus brauni, Dictyosphaerium pulchellum, Eudorina* sp. *Pandorina morum,* the protozoan *Tintinnidium* sp., and the microcrustacea *Daphnia* spp., *Diaptomus* spp. and *Epischura lacustris.* There is evidence that some of these, such as *Daphnia,* are killed by pollutants in the river, but for the most part they are species that nor-

mally live in the open lake and do not find river conditions suitable. The lack or impoverishment of these species in the highly polluted river water, therefore, is not incontrovertibly associated with the pollution alone.

A few forms were occasionally or regularly observed in larger numbers at station 1 than at the other stations. For example, shells of the protozoan *Arcella* were seldom seen except at this locality. For the most part, however, only empty shells of this benthic form were encountered, emphasizing its tychopelagic nature. Nematode worms likewise are typically bottom-living forms, and occur as plankters only accidentally, carried there by the currents. Unidentified nematodes were observed in much larger numbers at station 1 than elsewhere. On May 12, 1951, for example, the surface sample from station 1 contained the equivalent of 65,000 nematodes per cubic meter, and the deep sample contained the equivalent of 102,000 per cubic meter. On the same date at station 2 there were 400 per cubic meter at the surface and 600 per cubic meter at 6.5 m. No examples were seen at station 6, and at the surface at station 7. There were 100 per cubic meter at 6.5 m. at station 7. More were encountered, however, at highly polluted station 5 on this date, there being 32,000 per cubic meter at the surface and 100 per cubic meter at 6.5 m. Similar results were obtained on other dates during the winter and spring months. Nematodes were practically absent from all stations during the summer and fall. There is no reason to believe that nematodes in the lake plankton are indicative of pollution, but rather that they are indicative of water recently subjected to strong river currents. The largest numbers of these forms occurred during the months of heavy runoff. It is probably true that the species of nematodes involved are resistant to pollution, or they would not have occurred in such large numbers in the highly polluted water. However, insufficient data were gathered on conditions in the river in the present study to warrant any conclusions concerning their value as pollution indicators. Except for station 1, only a single plankton sample was collected from the river. This was obtained from a shallow-water station approximately 9.7 km. from the mouth of the river, on December 21, 1950. On this date the water at the surface at station 1 contained 18,000 nematodes per cubic meter, and at 6.5 m. there were 1,800 per cubic meter. The water at the other river station contained 84,000 nematodes per cubic meter, yet pollution at this point, although serious, was not as intense as at station 1.

Sullivan (55) reported that *Synedra* and some species of *Navicula* were more abundant in the water near the mouths of streams entering Lake Erie than they were in the lake itself, although the reverse was true for almost all other phytoplankton genera. In the present study *Synedra* was far more common than *Navicula*, but the two genera were not clearly separated in the counts, and have been reported together as "naviculoids." On some dates (January 5, March 3, June 23, July 7, September 3, and September 14, 1951) the water at station 1 contained more "naviculoids" than that at any of the other stations. On December 9, 1950, station 1 had larger numbers of these forms than any stations except highly polluted station 2, and on May 12, 1951, there were more than at any other station except highly polluted station 5. On the other dates station 1 water contained smaller numbers of "naviculoids" compared to the other stations. It seems probable, in view of the results reported by Sullivan and by other authors, that they are not indicators of pollution, but rather are indicative, under certain circumstances, of river conditions. Such forms, however, may also be of

great importance in the open lake, with no relation to river influences, as indicated in the present study in samples gathered on April 28, 1951, at the height of the vernal pulse of phytoplankton (18), and as indicated by several other authors who have dealt with the phytoplankton of the Great Lakes (9)(10)(11)(12)(14)(15)(25)(58).

From the foregoing it would appear that in situations similar to that investigated in this study, the presence or absence of particular species of plankton organisms is not a safe criterion of the presence or absence of pollution. The intrusion of lake water into the river mouth, and the extensive mass movement of the lake water itself, with the consequent translocation of differing plankton communities, results in an unclear picture. On the other hand, the presence of river water in the harbor and in the lake can be detected by the presence of such organisms as nematodes, or at times by relatively large numbers of "naviculoids." Pre-knowledge of the polluted nature of the river water thus allows an indirect means of the detection of pollution, although it is not a very sensitive means.

Plankton Condition and Pollution Source

Because of the known deleterious effect of many industrial wastes and domestic effluents, it was thought that there might be value in measurements of the condition of the plankton at the several stations. To this end, during analyses a record was kept of the dead or obviously moribund cells of some of the phytoplankton species, and of zooplankters that had obviously been dead at the time of collection.

In the case of the phytoplankters, dead and moribund cells originate from many causes, and not only from pollutants. For this reason the percentages of dead and moribund cells fluctuated greatly at all the stations. The average percentages for four of the most common phytoplankters are given in Table I. Of all the phytoplankters, the diatom genus *Melosira* was the most abundant, and was present through the greatest period of time. The proportion of dead and moribund cells of this form was significantly higher at highly polluted station 1 than elsewhere. The diatom *Asterionella* likewise exhibited a higher proportion of mortality at station 1. Results for the blue-green alga, *Aphanizomenon flos-aquae*, were somewhat unsatisfactory because the species occurred only during the late summer and fall months and was only very seldom observed at stations 1, 3 and 4, which were respectively in the most highly polluted and in the cleanest water. Results from the remaining stations do not show any significant variation.

The green alga, *Pediastrum simplex*, was of particular interest in that living coenobia of the species were virtually absent from the open lake stations during the winter, spring, and early summer, whereas they were present regularly at station 1 throughout the year. Often, when living forms were absent from the open lake large numbers of dead coenobia were observed. As a result of this, higher percentages of dead and moribund cells of this species were encountered in the open lake than at station 1. It might well appear as though during the winter and spring *P. simplex* found conditions suitable in the river for a relatively high productivity, and then was killed by the lake conditions, leaving nothing but dead coenobia. This, however, probably is not a fully correct interpretation, because the absolute numbers in the river were not very high, and could not contribute enough individuals to account for the often abundant coenobia found in the lake. It is suggested, therefore, that the cell walls of *P. simplex* are resistant to decay, and the dead coenobia were the

TABLE I.—Average Percentage of Dead and Moribund Cells of Four Phytoplankton Species

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6		Station 7		Station 8		Station 9	
	s[1]	d[2]	s[1]	d[2]	s[1]	d[2]	s[1]	d[2]	s[1]	d[2]	s[1]	d[2]	s[1]	d[2]	s[1]	d[2]	s[1]	d[2]
Melosira sp.	28.7	27.9	19.6	16.7	21.9	20.7	16.1	15.1	15.3	23.1	22.2	13.5	21.8	19.0	17.0	15.1	19.2	14.9
Pediastrum simplex:																		
Colonies	28.0	28.7	57.9	49.9	55.7	56.3	68.0	62.0	44.4	52.9	49.5	58.3	52.4	60.6	47.9	64.3	63.6	62.7
Cells	37.7	42.0	66.9	54.6	73.2	78.8	90.5	77.8	58.3	65.9	63.0	66.3	64.9	69.4	58.8	67.1	72.3	68.9
Asterionella sp.	20.3	16.0	9.1	9.7	16.9	12.7	11.4	16.0	16.5	14.4	11.9	10.9	15.2	13.7	13.3	13.9	17.2	13.1
Aphanizomenon flos-aquae	7.7	17.4	16.1	11.5	17.6	22.7	13.9	18.5	13.7	12.1	13.5	14.9	12.9	12.2	13.1	10.8	14.3	10.8

[1] Surface sample.
[2] Deep sample.

remainder of the autumnal bloom of the species in 1950. It is suggested also that the warm water of the Cuyahoga River in winter and spring (from industrial cooling effluents) (20) allowed a limited productivity in that location.

Zooplankters were not common in surface samples from station 1. At times they were abundant in the bottom sample, however. Much greater mortality, especially of the *Cladocera* and of *Copepoda*, was indicated at station 1. At times dead zooplankters were numerous, whereas at other stations only individuals here and there were encountered that were obviously dead or moribund at the time of capture. For example, on October 13, 1950, 8 juveniles of *Cyclops* were observed at the surface at station 1, of which 5 were obviously dead at the time of collection; 3 juveniles of *Diaptomus* were seen, of which 2 were dead; and 3 juveniles of *Daphnia longispina* were collected, of which 1 was dead. Of the few specimens collected in the deep sample at station 1 on this date, one-third were dead. *Copepoda* and *Cladocera* were many times more abundant at other stations than at station 1 on this date, but only a single dead *Daphnia* was seen—at station 5, which itself is highly polluted. Zooplankters were very common at all stations on September 14, 1951. Four dead specimens were encountered at the surface at station 1, out of a total of 38 *Cladocera* and *Copepoda*. The proportion in the deep sample was 4 out of 142. Not a single dead specimen was seen elsewhere. On June 23, 1951, conditions were similar to the last mentioned, except that the proportion of dead zooplankters at station 1 was much higher (the exact proportion could not be determined because of the disintegrated condition of the dead specimens).

From the foregoing it follows that, in regions where polluted water enters large lakes from rivers, the presence

of proportionally larger numbers of dead and moribund phytoplankton cells is to be expected in the most highly polluted water, but these conditions are not a reliable indicator of pollution or of the degree of pollution, because other environmental factors than the pollutants also cause death. Highly polluted water can be indicated by the presence of dead *Copepoda* and *Cladocera* among the zooplankters. Other methods, however, are more reliable and more delicate indicators of pollution.

More important is the destruction of plankton organisms by pollutants. The full extent of the destruction undoubtedly is not shown in the foregoing, however, as indicated, for example, by results reported by Anderson (2), who described death in *Daphnia magna* often only after many hours of subjection to toxic pollutants.

Discussion and Conclusions

Although it is probable that plankton organisms are useful indicators of polluted conditions in ponds, small lakes, and small bays of larger lakes, the results of this study suggest that they are not reliable indicators in large bodies of water, because of the great diluting effect of the lake water, and the consecutive appearance at any particular point in large lakes of several water masses, each with its own distinct planktonic fauna and flora. When the major portion of the pollution load enters such large lakes from rivers, as in this present case, the plankters are even less reliable as pollution indicators, because of the great differences of productivity of the river and lake waters. Nevertheless, with knowledge of the existing differences between the standing crops and the species of plankton in the river and the lake, respectively, the presence of water derived from the river sometimes can be detected in the open lake, and in this way an indirect indication of pollution can be attained. Chemical analyses of the water, on the other hand, give much more sensitive indications of the presence of river water and of pollutants, and in general are more easily performed, than plankton analyses. The use of plankton methods, therefore, is not recommended for the detection of pollution in large lakes.

On the other hand, definite effects of pollution upon the plankton can be shown. In the present study, the fertilizing effects of pollution were not clearly indicated, because of the slow response of the plankton. By the time the plankton could respond to the fertilizers the polluted water would be mixed with a large volume of Lake Erie water, and thus could not be detected in the limited area investigated. It is to be expected, however, that a more extensive investigation would uncover a richer plankton growth in the general vicinity of the pollution sources than at a considerable distance away. A thorough quantitative study of the plankton of wider areas of the central basin of Lake Erie has never been reported, and is needed before any definite fertilizer effects of domestic and industrial effluents can be determined.

The detrimental effects of the pollutants could be observed, especially at station 1, in the death of phytoplankters and of zooplankters, and was especially notable in the case of the latter. Precise analysis of the amount of harm done, and of the geographical extent of the distribution of poisonous effluents in toxic concentrations, fell beyond the limits of the present study. Of the possible toxic industrial ions, only Fe^{++} and Fe^{+++} were analyzed, the former qualitatively only. The toxicity of iron has been reported variously in the literature, and its effects have not always been distinguished clearly from the effects of low pH values resulting from the hydrolysis of the iron salts

(24). The toxicity threshold of $FeCl_3$ for *Daphnia magna* has been reported (2) to be 0.00011 M(6 p.p.m. Fe) when the solution was made up in Lake Erie water. In the Cleveland Harbor area (17)(20), concentrations of soluble iron greater than this value were confined to station 1. Other investigators have reported iron to be toxic to fish in quantities from 0.1 to 1.0 p.p.m. In the Cleveland Harbor area, a soluble iron content of 0.1 p.p.m. or greater was observed at all of the stations, although only twice during the year at station 4. The toxicity of iron salts in soft water has been reported to be greater than in hard water (35), probably because of the greater acidity of the former solutions. Lake Erie is a moderately hard-water lake, and thus the toxicity would be less than maximum. Except occasionally at station 1, the pH was never found to be excessively low in the Cleveland Harbor area (17)(20). Small quantities of iron are not necessarily detrimental to organisms; they have been shown (32) to be necessary for the proper growth of diatoms. Davis (16) has described waters heavily polluted with Fe and other effluents with a high productivity of phytoplankters. This also suggests the relatively benign character of reasonable quantities of Fe in industrial effluents, but the whole problem demands much further investigation (31).

A number of lines of further investigation are suggested by the results reported herein, and by the problems that remain unanswered. Among the more important are: (a) to make a study of the effects of individual effluent substances upon individual plankton species, including a more detailed study of the toxicity of the important pollutant, iron; (b) to study the bottom fauna and flora in relation to pollution; (c) to study in detail the mixture of Cuyahoga River water with the lake water, and to trace the river water by refined chemical means to determine the extent of pollution effects; and (d) to investigate the relationship between plankton productivity and the numbers and quality of the fish population, especially as this relates to pollution problems.

Summary

Nine stations in the Cleveland Harbor area of Lake Erie were visited every two weeks during the year September 1950 through September 1951. Quantitative plankton samples were obtained from the surface and from the 6.5-m. depth at each station. In the Cleveland Harbor area, the major portion of the industrial effluents, and an important volume of the domestic effluents, enter Lake Erie through the Cuyahoga River.

The quantity of the plankton was uniformly small at those stations where the pollution (as indicated by the Fe content) was greatest, but apparently this was associated with the lower productivity of the river, rather than directly with the pollution. Small plankton quantities were also encountered in unpolluted water. Therefore, it is thought that the standing crop of the plankton is not a reliable index of pollution in localities such as that under investigation.

Some common plankton species were lacking, or were rare, in the most highly polluted water. Other forms (mostly tychopelagic) that were common at polluted stations were rare or lacking elsewhere. Again, however, it is probable that these phenomena were the result of river conditions and not the result of pollution. Therefore, in locations such as the Cleveland Harbor area, the presence or absence of particular plankton species is not a reliable index of pollution.

Examples are given of species of phytoplankton and zooplankton which occurred more frequently in a dead or moribund condition at the more highly polluted stations than elsewhere.

These are considered to be indicators of pollution. However, other means are more sensitive detectors, and more easily applied. That the harmful effects of effluents is important is shown by the death of plankters, and it is proposed to investigate these effects more closely.

Acknowledgments

The project reported herein was supported by funds allocated by the State of Ohio, administered through the Franz Theodore Stone Institute of Hydrobiology of Ohio State University and by the loan of essential equipment directly from the Institute.

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THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

OPERATION REPORTS

Another fiscal year has come to a close and it is time to take stock of what has been accomplished during the preceding twelve months. Many treatment plant superintendents will be preparing their annual reports. Those who operate on a calendar year should take heed, because their day will be here all too soon.

You won't dread the task if you have had the foresight to keep complete records. Many excellent methods of keeping records have been presented in previous issues of THIS JOURNAL. In addition to records, the daily log or plant journal is very helpful. Here is an excellent memory refresher. Events, projects, ideas, and data should be recorded throughout the year.

The annual report itself should present a concise picture of the year's operation. High points should be emphasized and a summary budget presented. Careful thought must be given to this part of the report. It should make the best appearance possible. The busy citizen or official wants to know what was done, what it cost, and what is in prospect for the coming year—which by the time he receives the report, is well under way. If the report is well done, he will read on.

The second portion of the report should include pertinent information on the operation of the treatment units. Descriptive material on significant details of operation should not be omitted. An introductory paragraph on the plant layout is desirable—because there are always new readers.

Well-prepared tables presenting complete summary data on month by month operation should be included. Each well-kept record is a building block in the structure of better plant operation. This yearly report constitutes the basis for a thorough analysis of your plant.

There is a need for good reporting of sewage treatment plant operations. However, the problems appear to be how to encourage report preparation and how to disseminate effectively the pertinent points of these reports.

Extracts of the interesting reports as presented in the "Operator's Corner" of THIS JOURNAL are an attempt to obtain a wider coverage of these reports. They also serve to let interested persons know what is being done in the various plants throughout the country. Sometimes we wonder if anything is accomplished by these extracts or if more could be accomplished through some other approach. Perhaps a combination of methods would aid in bringing operators together in a closer bond.

What can the "Corner" do to aid in this phase of plant operation? The answer depends upon *you*. D. P. S.

SEWER SERVICE CHARGES AT CHARLOTTE, NORTH CAROLINA *

By Robert S. Phillips

Assistant Superintendent, Charlotte Water Department, Charlotte, N. C.

Many communities do not make any special charges to industry for the treatment of industrial wastes of unusual strength, and many municipalities accept the responsibility for treatment of these wastes without standards for admission into the sanitary sewer system.

Hazen (1) in an excellent analysis of the problem, points up the difficulties of equitable distribution of costs, and states that communities generally have considered the cost of waste disposal as a public obligation to be borne by the community as a whole. Recently, however, the demands for new and increased municipal services, as well as rising costs, without corresponding new sources of revenue, has compelled many municipal administrators to reassess the costs of waste disposal. It is probably for this reason that many cities have in recent years adopted sewer service charges based wholly on volume, as measured by water consumption, to supplement or supplant inequitable ad valorem sewer taxes. The concept of charges based on strength and volume is still more recent and represents a further step in an attempt to assess realistically charges in proportion to the service rendered.

In North Carolina only a few municipalities, apparently, have considered the possibility of levying special charges on industry for the treatment of industrial wastes based on quantity and strength. Some communities, such as Salisbury, N. C., have worked out special contractual arrangements with industry for the treatment of commercial wastes. Some cities levy a sewer service charge on all users, based on a flat percentage of the water bill, to cover the operating costs of sewage treatment and sewer upkeep. Recently, Winston-Salem, N. C., adopted an ordinance which levies a 50 per cent charge, based on the water bill, "For the purpose of paying all expenses of operating, managing, repairing, and maintaining the sewage disposal system and to pay the principal of and the interest on the bonds issued for such system . . ." (2).

Other cities outside North Carolina provide special charges to industry for treatment of industrial wastes. In general, these charges are based on volume together with suspended solids, B.O.D., and/or chlorine demand; in other words the additional loading imposed on the sewage system. The suspended solids load alone is usually considered when plant facilities for primary treatment and sludge disposal are required. Where chlorination is practiced the excess cost of this treatment is sometimes properly charged to industry. Where a high degree of purification is required, and large or elaborate secondary treatment facilities must be provided, the B.O.D. loading is important in allocating charges for costs. It is for these and various other reasons, that special charges may vary greatly from one community to another.

Several years ago Charlotte, N. C. adopted an industrial waste ordinance (3) establishing standards for admission to the sewers of commercial liquid wastes and providing special charges to industry for the service. This ordinance was adopted prior to the enlargement of the sewage treatment

* Presented at 1954 Annual Meeting, North Carolina Sewage and Industrial Wastes Assn.; Asheville, N. C.; Nov. 8–10, 1954.

plants, and will become effective upon completion of this work in 1955.

The evolution of the ordinance came about in an interesting way. Prior to 1950 an ordinance had been proposed that would have required many industries to pretreat their wastes before discharging into the sanitary sewers. Standards proposed for admission of the wastes were comparable to domestic sewage characteristics, although more liberal. In exchange, the responsibility for final treatment of the wastes would have been accepted without any additional charge beyond the normal sewer service charge of 25 per cent of the water bill.

This proposed ordinance was vigorously opposed by most of the industries. Many industrialists honestly felt that the magnitude of the problem had been over estimated. And they contended that the combined wastes could be treated more economically and efficiently in two large municipal treatment plants than in a large number of small pretreatment plants. As a result, the City of Charlotte, N. C. with the advice and agreement of industry, employed a consulting engineering firm to investigate and report on the industrial wastes problem. Highlights of the final report (4) were:

1. That the industrial wastes amounted to about 2 m.g.d., with a population equivalent of 65,000 persons. The strength of the combined waste was increased about 45 per cent above domestic sewage alone.

2. That the existing plants, while inadequate, were adaptable for expansion and continued use.

3. Recommendation that combined treatment of industrial and domestic sewage wastes would be most economical and practical.

4. Recommendation that industries be required to equalize industrial waste flows over a 24 hr. period.

5. Analyzed the cost of enlarging the municipal treatment plants, and compared the cost of treating domestic sewage with the cost of treating combined sewage and industrial wastes.

As a result of this report, and subsequent agreement by the industries concerned, the city council adopted the present ordinance, which specifies that:

1. All wastes shall be admitted into the sanitary sewers without pre-treatment, provided specific standards are met.

2. Industrial wastes shall be neutralized, and relatively large flows shall be equalized over a 24-hr. discharge period.

3. Complete treatment facilities shall be provided for all domestic sewage and industrial wastes admitted to the sewers.

4. The industries would pay for all costs incurred in enlarging the treatment plants, and treating industrial wastes having a B.O.D. in excess of 250 p.p.m. All users of the sewers, whether industrial or domestic, would continue to pay a sewer service charge based on 25 per cent of the monthly water bill.

The cost to industry for the treatment of industrial wastes will be based on the excess load as measured by the B.O.D. and volume discharged into the sanitary sewer. When the B.O.D. of the wastes is more than 250 p.p.m., the total monthly surcharge to industry will include:

1. A surcharge of $23.34 per 1,000 lb. of excess B.O.D. to cover all fixed charges and amortization costs of the additional plant investment required.

2. A surcharge per 1,000 lb. of excess B.O.D. to cover operating costs. This surcharge will be fixed annually and computed from the actual operating costs experienced during the preceding year. Costs incidental to inspection, sampling, and analyzing the wastes will be included in this surcharge. It is expected that the sur-

charge will be $12 to $15 per 1,000 lb. of B.O.D.

As a practical illustration of this system of charges, a food processing plant will pay approximately $180 per month for discharging 104,720 g.p.d. of wastes. The waste is highly caustic with a B.O.D. of 466 p.p.m. Under the ordinance this industry will be required to equalize its flow over a 24-hr. period and neutralize the causticity at its own expense. At present, the waste is discharged into the sewers uncontrolled and is not neutralized. The sewer service charge to the industry now averages $70 per month. When the ordinance takes effect there will be an additional monthly surcharge to this industry estimated as follows:

For waste treatment plant amortization	$110
For waste treatment plant operating costs *	71
Total Surcharge	$181

* Estimated $15 per 1,000 lb. B.O.D.

The industrial wastes will be sampled at least once each quarter and the B.O.D. strength determined. The volume discharged will be based on water consumption as shown by the water meters. Separate bills for the surcharge will be rendered monthly by the municipal billing division.

In conclusion it should be pointed out that the ordinance is not considered as the "last word" or necessarily recommended as a model for other communities. It represents one approach to the problem and seems best suited for this particular situation. Others will undoubtedly find other means better suited to their conditions. Practical administrative experience has not been obtained, since the ordinance will not go into effect until 1955. Time and experience may dictate some changes.

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OPERATION OF A PHENOL RECOVERY PLANT *

BY H. A. KJELLMAN

Process Engineering Section, Tar Products Div., Koppers Co., Inc., Pittsburgh, Pa.

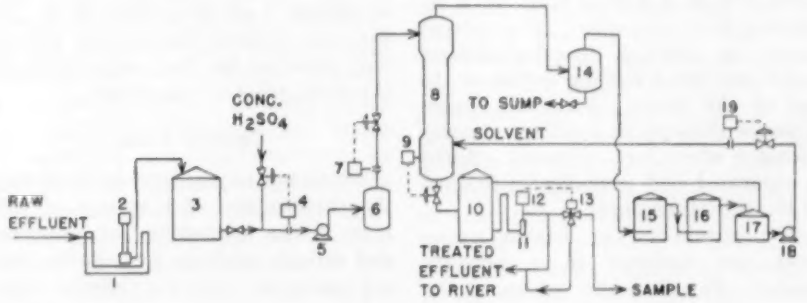
The operation of a plant to recover a minimum of 98 per cent of the phenols from the effluent of the Koppers Company industrial facilities at Follansbee, W. Va. presents problems of emulsion formation and time-consuming control tests that were effectively met. To handle the troublesome recovery problem of phenols, a continuous counter-current solvent extraction plant was constructed. This unit is regularly meeting and bettering the required recovery efficiency specified by the state water commission for discharge to the Ohio River. In addition, considerable quantities of saleable phenols are recovered which contribute substantially toward making the treatment self-supporting.

* Presented at 1954 Annual Meeting, West Virginia Sewage and Industrial Wastes Assn.; Huntington, W. Va.; Nov. 9–10, 1954.

At Koppers' Follansbee plant, coal tar and tar oils are processed producing road tars, industrial pitches, creosote, and coal tar chemicals. Water, which is present in the crude raw materials, and that which comes in contact with raw materials or products during the processing will contain phenol and other tar acids. The majority of the contaminants in the process water from the plant therefore are similar to those found in the ammonia liquors at byproduct coke plants. As traces of phenols are so objectionable in streams which are used as a source of municipal water supply, an interest developed in their reduction at Follansbee in the late 1930's as a result of an awakening realization of the problem there. World War II delayed action on a proposal developed by Koppers at that time. As a result of changes in effluent load and dephenolization requirements, this proposal was discarded after the war as inadequate. By then the subject was receiving considerable attention from the state water commission of West Virginia and the newly formed Ohio River Valley Water Sanitation Commission. After consideration of the various methods by which the necessary dephenolization requirements might be met, a continuous counter-current solvent extraction process was proposed and a pilot plant constructed. The current commercial unit has evolved from that plant.

Plant Description

The flow diagram of the phenol recovery plant (Figure 1) installed at Follansbee provides for the collection in a sump of the contaminated effluent originating from the various sources. At this point, oil and settleable solids are removed by a decanting and skimming system. From the sump the effluent is pumped intermittently to one of two storage and feed tanks which contain a bed of solvent on the surface of the contained effluent. This solvent layer serves as a scrubbing media to remove any remaining traces of oil or tar missed by the settling sump. The raw effluent is drawn at a controlled rate from storage and its alkalinity adjusted by the addition of concentrated sulfuric acid. This acid



1—Collecting Sump
2—Sump Pump
3—Feed Storage Tank
4—Controller, pH
5—Feed Pump, 210-G.P.M. Capacity
6—Filter
7—Raw Effluent Flow Recorder-Controller
8—15-Tray Koch "Kaskade" Column
9—Interfacial Level Controller
10—Continuous Decanter Tank
11—Treated Effluent "Rotameter"
12—Sample Controller
13—3-Way Solenoid Valve
14—Auxiliary Cleanup Decanter
15—Primary Washer
16—Secondary Washer
17—Solvent Pumping Tank
18—Solvent Pump, 310-G.P.M. Capacity
19—Solvent Flow Recorder-Controller

FIGURE 1.—Process flow diagram for phenol recovery utilizing a continuous counter-current solvent extraction process.

is pumped from storage at a rate regulated by a pH controller. The effluent then passes to a feed pump which discharges through a filter removing any solids contained in the effluent or tars thrown out by acidification. Periodically, the filter is backwashed and the solids removed to an adjacent sump. The waste water passes from the filter to the top of a 15-tray Koch "Kaskade" contactor. It descends through the tower contacting an ascending stream of solvent which extracts the contained phenols. The dephenolized effluent enters a settling section at the base of the column and passes from the column to a continuous decanter through a flow-control valve which is actuated by an interfacial level controller located in the base of the tower. Residual traces of free solvent are continuously decanted at this point to the solvent pumping tank. The effluent discharges through a continuous sampling and metering device to a sewer which discharges to the Ohio River. The extracting solvent is pumped from the solvent pumping tank to the dephenolizing tower by a centrifugal feed pump. The feed rate is measured and controlled at a desired level by a recording flow controller. The solvent passes up through the dephenolizer tower and into a settling section at the top of the tower. From the tower it passes through an auxiliary cleanup decanter where any entrained effluent is separated and periodically drained to the collecting sump.

The phenol-bearing solvent passes from the decanter to a primary washer. It enters the bottom of the washer through a distributing pipe and plate, bubbles up through a fixed caustic soda bed, and overflows near the top of the washing tank. The partially dephenolized solvent drains by gravity to the bottom of a secondary washer where it comes in contact with caustic soda in a similar manner. The dephenolized solvent is continuously decanted from the top of the secondary washer and returns to the solvent pumping tank for re-use in the process. When the caustic soda bed in the primary washers becomes essentially saturated with tar acids, the operation is shut down while the solution of acids in caustic is pumped to the tar acid processing section of the Follansbee plant. A fresh bed of caustic soda is then placed in the washer. The flow sequence of the solvent to the washers is then reversed with the one containing the fresh caustic solution now serving as the secondary washer.

TABLE I.—Typical Process Data for the Phenol Recovery Plant

	Flow (g.p.m.)	Phenol Content (%)
Raw effluent	120	0.700
Treated effluent	120	0.006
Solvent:		
To "Kaskade" tower	210	0.064
From "Kaskade" tower	210	0.460
From primary washer	210	0.130

Table I presents typical processing performance for this extraction system. The flow rates given are those for which the plant was initially designed. Actual performance has been at effluent feed rates from 60 to 170 per cent of these figures, and solvent flow variation has been approximately the same order of magnitude.

Control Tests

Of major importance in analyzing the performance of a system of this type is the availability of practical and reliable methods for effluent phenol analysis. In the effluent phenol concentration ranges encountered, the most satisfactory test method available at the time of the pilot plant study was the bromine turbidimetric method. This test was used during the study period and the initial phases in starting up this unit. Recently the distilled 4-aminoantipyrine method was placed in use because it was equally

as rapid as the bromine method. The plant operator could readily handle the test procedure, and more reliable results were obtained under certain circumstances. Normal experience has been that the results of these two methods are in relatively close agreement when done by experienced analysts.

The presence of tar bases, which are often present as contaminants in effluent samples, can create interference in the bromine turbidimetric method results, unless extreme care is taken. This fact and the improved accuracy at low phenol concentrations has caused the present switch to the D.A.A.P. method. Initial analyses were performed using phenol as the colorimetric standard. This gave a lower than actual phenol content for the wastes, because of the presence of alkylated phenols which are less reactive in the test procedure concerned.

To obtain a more accurate picture, both test methods were modified to the extent of making up the stock solutions for the development of the colorimetric standards with a mixture of phenols reconstituted to correspond with those normally present in the general plant waste waters. However, in the extraction step the alkylated phenols are preferentially removed from the effluent due to their higher distribution coefficients. As might be expected, therefore, the ratio of the residual phenols contained in the treated effluent varies from that in the raw effluent, and the residual effluent phenolic contaminant is primarily phenol. Rather than complicate plant analytical procedures, the choice was given to a single colorimetric standard for all plant effluents. Consequently, the treated effluent phenol analyses reported are somewhat conservative and run about 50 per cent higher than the true value. The extraction efficiencies reported are slightly low.

Emulsion Formation

In an extraction system of this type one of the prime points of concern is the possibility of emulsion formation or unsatisfactory settling characteristics. Emulsions or slow settling characteristics in either the effluent-solvent contactor or the solvent caustic soda contactor can seriously reduce recovery efficiencies and may force the unit to shutdown. In many phenol solvent extraction plants described in the literature, comments are found regarding the problems created by emulsions or special care taken in the contacting step to prevent their formation. In this case special efforts were made to eliminate possible emulsion formers prior to treatment of the effluent. Care is taken to decant oil and solids from the collected effluent before pumping it to storage. This oil decanter was designed in general compliance with the American Petroleum Institute recommendations for petroleum oil waste water decanters.

The design procedure set up for lighter than water petroleum oils had to be modified to accommodate the heavier than water coal tar and coal tar oils. The effectiveness of this decantation step probably can be appreciated best by noting that over 30,000 gal. of oil per year are recovered at this point. In further pretreatment the crude effluent is discharged into the storage tanks through a layer of several feet of light oil whose function is to scrub out traces of entrained and emulsified oils. This prevents oil carryover to the effluent contactor where it might be absorbed in the process solvent gradually causing deterioration. An additional treatment for emulsion prevention is the acidification and filtration step ahead of the contacting tower.

Some emulsion problems were encountered in the pilot plant operation. Wastes were periodically encountered which caused effluent carryover in the extracting solvent. Methods developed

for handling the problem were designed into the commercial unit. These included sufficient capacity to permit operation at greatly reduced throughputs, dilution of troublesome wastes with large quantities of non-emulsifying wastes, acidification and removal of entrained oils and solids. Acidification tends to break the emulsifying characteristics of the wastes. A further effort along this line was a design change in the extracting column whereby the column tray spacing was increased to 30 in. from the 24 in. spacing used in the pilot plant.

An empirical test developed during the course of the work permits rapid evaluation of the settling characteristics of the solvent-effluent and the solvent-caustic soda systems, and evaluates the effect of measures taken to control the settling rates. In the commercial plant there has been no effluent carryover in the solvent. This has been quite gratifying, considering the efforts made to eliminate that particular problem. The solvent currently in use consists primarily of aromatic hydrocarbons and has the following general characteristics:

Boiling range	150°–200° C.
Specific gravity	0.88
Flash point	100° F.
Phenol distribution coefficients:	
As received	1.1–2.4
With 2 per cent tar bases	5–7

The choice of this solvent is primarily one of economics and suitable distribution coefficients. Any other solvent giving a satisfactory over-all solution to the problem would be acceptable. The pilot plant operations used a solvent consisting of No. 2 fuel oil fortified with tar bases boiling over 240° C. In the commercial plant, the use of an aromatic solvent which was self-fortifying with respect to tar bases became desirable from the viewpoints of both economics and stream contamination.

The "Kaskade" tower has given satisfactory performance over a rather extended operation range (Table III). There is little effect on column performance at widely varying throughputs.

TABLE III.—Capacity-Efficiency Test on the "Kaskade" Tower

	Test Runs*		
	1	2	3
Effluent rate, (g.p.m.)	180	150	120
Solvent rate, (g.p.m.) (1.75 × effl. rate)	315	260	210
Tar acids:			
Effluent in (p.p.m.)	4,975	5,180	5,530
Effluent out (p.p.m.)	63	56	55
Dephenolization (%)	98.7	98.9	99.0

* All runs of 4-hr. duration at pH 7.8.

The current limitation on the degree of extraction obtained by this process at Follansbee is due to the residual phenol content of the washed solvent fed to the dephenolizing tower. The solvent leaving the secondary washer is approximately in equilibrium with the phenol-bearing caustic solution. One might expect, therefore, a change in the amount of dephenolization in the Koch tower with the degree of saturation obtained in the washer. This is the case and as the washers become more saturated with phenols, extraction efficiency drops off. Under actual operating conditions it has been found practical to operate until the primary washer becomes 85 per cent saturated with phenols before replacing the exhausted caustic solution in the primary washer with fresh caustic solution.

A second limitation applying to this specific installation is the use of regenerated caustic from a lime-soda caustic plant operated at Follansbee. The caustic soda from this source contains several per cent tar acids. As mentioned previously, an equilibrium relationship exists which prevents complete removal of the phenol from the solvent. These two limitations have established a level of 40 to 50 p.p.m. phenols as a minimum that can normally be reached with this plant. It has been calculated that using a 3-stage

washer and starting with fresh caustic solution containing no phenols, the residual phenol content of treated effluent might be reduced below the 10-p.p.m. level.

In any phenol removal plant consistent operation at high efficiencies is required. Experience to date with this unit has demonstrated its reliability in treating effluent to a satisfactory degree of dephenolization.

Previous mention was made that this unit is economical to build and operate. Construction costs of this type of equipment, including all process equipment and storage tanks but excluding the effluent collection system, are estimated at about $2.00 per gallon daily effluent treatment capacity. Direct operating expense is estimated at less than $1.80 per 1,000 gal. treated effluent and its three major cost components are:

1. Depreciation and taxes.
2. Labor (one operator per shift).
3. Solvent make-up.

The plant is attended by one operator who also performs all of the analytical work for the process.

No plant or general overhead costs are included in this estimate. The value of recovered phenols, which varies with the degree of effluent contamination, is not credited against this direct operating expense. It should be noted that the foregoing costs pertain to this plant, where recycle caustic soda is available at cost from a lime-soda caustic plant, and where local disposal of the recovered tar acids is possible.

INTERESTING EXTRACTS FROM OPERATION REPORTS

"All habits are stepping stones—some lead up, others down."—*Anon.*

Attention operators! It will be appreciated if copies of all annual reports of both large and small plants are sent to the Federation office for abstracting in this section of the Journal. Carbon copies of typewritten reports will be promptly returned on request. Please direct annual reports to: Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Second Annual Report of the Noblesville, Indiana, Sewage Treatment Plant, December 31, 1953

By Albert Shoaf, *Superintendent*

This brief annual report was prepared to introduce the sewage treatment plant to the citizens of Noblesville, Indiana. The report is prepared in a simple style without detailed operation data. Although mimeographed and folded as a booklet, the report has an attractive printed cover on green stock and includes a flow diagram of the treatment plant.

Noblesville is a city of 7,000 located on the White River in central Indiana. Activated sludge provides adequate treatment for a design load of 0.8 m.g.d. Flow during 1953 averaged 0.64 m.g.d. from an estimated connected population of 6,500. Three sewage pumping stations are in the collection system.

Total cost of the treatment facility

for the year amounted to $46,964.45 and included salaries, supplies, utilities and interest on the bonds. Operating cost alone averaged $100.00 per m.g. Receipts from sewer service charges amounted to $41,995.30. A balance carried over from the previous year prevented a deficit operation. Collection of the service charge has not been 100 per cent satisfactory. Service charges were increased 10 per cent during the year to a minimum of $1.65 per month. A staff of four maintains the entire system.

Treatment efficiency averaged 93 per cent over-all reduction in B.O.D. and 95 per cent reduction in suspended solids. The dissolved oxygen content of the effluent was 4.0 p.p.m. with a pH of 7.2. Digester gas production averaged 4,000 cu. ft. per day. One of the five burners in the boiler of the digester heater was converted to digester gas, resulting in a saving of approximately 2,000 cu. ft. per day of natural gas.

Problems included stoppages in the diffuser tubes of the aerators, grit in the plant units and grit and debris in the pumping stations. As an interesting side light the final clarifiers were stocked with fish. The plant was visited by sanitary engineers from several foreign countries.

Editor's Note:

This report is given to call attention to the fact that every sewage treatment plant is worthy of the public relations value of an operation report. There is no municipal plant so small that it can afford to remain hidden and neglected.

Annual Report of the District of Columbia Sewage Treatment Plant for the Fiscal Years 1953 and 1954 *

By Hugh A. Schreiber, *Superintendent*

The average daily flow decreased 5 per cent in 1953 and 3 per cent in 1954 to 159.4 m.g.d. from a flow of 172.7 m.g.d. reported in 1952. Construction of the sludge disposal plant was expected to be completed by the end of 1954. Plans for the chlorination building finally reached the construction stage when a contract was let in January 1954.

Pilot-plant experiments with modified aeration were resumed during 1953. Contracts for the secondary treatment facilities were expected to be ready early in 1955.

General supervision of the District of Columbia institutional sewage treatment plants in Virginia and Maryland was continued.

Treatment

The steady increase in volatile matter, from 11.5 per cent in 1952 to 23 per cent in 1954 is indicative of a material change in the character of the grit removed by the plant. There is a large variation in velocity in the channels depending upon which main sewage pump is discharging. Channel capacity should be increased to remove the fine grit effectively.

A slow but steady decrease in the amount of night soil received indicates progress in the removal of privies.

An increase in municipal ground garbage from 4,043 tons in 1953 to 7,417 tons in 1954 is reflected in a higher B.O.D. loading and equivalent population. Garbage grinding was started late in 1952 and the tonnage has increased steadily.

Elutriation of the digested sludge with Potomac River water was changed in September, 1954 from the countercurrent method to two-stage wash. This change was made to facilitate operation of the system and has been satisfactory. Sludge is more consistent, but the wash water ratio has increased from 1.4 to 2.6. The filtered

* For last previous extract see This Journal, **25**, 11, 1359 (Nov., 1953).

TABLE II.—Summary of Operating Data for the Fiscal Years 1953 and 1954, District of Columbia Sewage Treatment Plant

Item	Average 1953	1954
Sewage flow (m.g.d.)	163.8	159.4
Equiv. pop.	1,038,500	1,031,000
Grit removed (cu. ft./m.g.)	1.6	1.5
Solids (%)	70.5	66.8
Volatile (%)	18.3	23.0
Suspended solids:		
Raw sewage (p.p.m.)	207	178
Effluent (p.p.m.)	81	79
Reduction (%)	60.9	55.6
B.O.D., 5-day:		
Raw Sewage (p.p.m.)	139	142
Effluent (p.p.m.)	94	98
Reduction (%)	32.4	31.0
Raw sludge:		
Removed (lb., dry/day)	169,940	128,600
Solids (%)	7.5	7.5
Vol. solids (%)	66.8	69.7
Grease (%)	19.9	21.6
Scum:		
Removed (g.p.d.)	17,353	16,937
Solids (%)	13.0	10.9
Volatile (%)	89.1	90.7
Sludge digestion:		
Vol. solids added daily (lb., dry)	117,549	92,780
Dig. sludge removed (g.p.d.)	70,000	89,900
pH, dig. sludge	7.4	7.2
Temp., dig. sludge (°F.)	93.6	88.2
Grease, dig. sludge solids (%)	6.2	7.3
Susp. solids, supernatant (p.p.m.)	20,070	15,400
Sludge gas:		
Total prod. (cu. ft./day)	778,000	745,000
Used (cu. ft./day)	589,000	493,000
Wasted (cu. ft./day)	189,000	252,000
Produced (cu. ft./cap./day)	0.8	0.7
B.t.u., gross (per cu. ft.)	653.6	650.1
B.t.u., net (per cu. ft.)	600.9	596.2
Methane (%)	60.5	60.7
Carbon dioxide (%)	33.8	34.4
Elutriated sludge:		
Solids (%)	8.4	7.9
Vol. solids (%)	42.8	45.9
Ratio, wash water to sludge vol.	1.4	2.2
Alkalinity, dig. sludge (p.p.m.)	3,311	3,310
Alkalinity, elut. sludge (p.p.m.)	728	728
Effective wash-water ratio	3.6	3.5
Elutriate:		
Susp. solids (p.p.m.)	3,773	3,600
Alkalinity (p.p.m.)	1,606	1,530
B.O.D., 5-day (p.p.m.)	917	1,000
Sludge dewatering:		
Dewatering time, total (days)	215	241
Filter hours, total	3,821.6	4,115
Cake produced, total (tons, wet)	21,784.5	25,937
Solids in cake (%)	30.0	28.6
Dry solids in cake, total (tons)	6,535.7	7,420.1
Yield of solids (lb./sq. ft./hr., dry)	6.8	7.2
$FeCl_3$ (%)	4.0	4.6
Susp. solids in filtrate (p.p.m.)	196	118
Operation and maintenance cost, total	$353,000	341,729

sludge is disposed of in part to the Department of Corrections and the remainder is trucked away by farmers and government agencies.

The 10 per cent nylon—90 per cent wool filter cloths were replaced in 1953 after 1,100 hr. of use. Two of the four replacements were 100 per cent nylon. Nylon cloths were more durable, but had a tendency to be blinded more quickly. After 1,060 hr. all cloths were replaced in 1954 with 10 per cent nylon—90 per cent wool material.

Laboratory work increased considerably during 1954, reflecting in part the increase in the river sampling program. Additional samples were collected during a two months' period when a large interceptor sewer was by-passed.

Operating Costs

Operating costs of this 175 m.g.d. primary treatment plant are distributed to actual sewage treatment functions. Power plant operation is charged 85 per cent to electrical energy and 15 per cent to plant heating.

Operational charges for pumping and treating the sewage and handling the sludge cake are compared below for 1953 and 1954:

	1953	1954
Quantity, total (m.g.)	59,843	58,244
Cost:		
Treatment ($/m.g.)	4.70	4.41
Pumping ($/m.g.)	1.41	1.55
Sludge cake disposal ($/ton)	1.24	0.62

Operating data for the fiscal years 1953 and 1954 are summarized in Table II.

1953 Annual Report of the Cincinnati, Ohio, Sewage Disposal Program

By A. D. Caster, *Sewage Disposal Engineer*

The sewage treatment program for the Cincinnati Metropolitan Service Area moved into high gear with the completion of the Little Miami sewage treatment plant and the start of construction for the Mill Creek facilities. Both of these events were celebrated in a Clean Water Rally Program on Oct. 6, 1953.

The first "Five Year Report" was published, giving a complete account of the funds collected and spent on the Metropolitan Sewage Disposal Program. Personnel employed in the Sewage Disposal Section was practically doubled, although there was still a need for junior engineers.

After many conferences, officials of the Ohio Board of Health and the Water Pollution Control Board delegated to the Sewage Disposal Section of the City of Cincinnati the responsibility of policing and controlling the discharge of wastes into the waters of the state within the Cincinnati Metropolitan Service Area. The limits for discharge to state waters as set up by Cincinnati city ordinance were accepted by the state agencies as applicable in the service area.

Budget and Accounting

Accounting records for the Little Miami sewage plant were established to control expenditures, depreciation and replacements. A card system was planned based on the "Uniform System of Accounts for Sewer Utilities." In addition, complete accounts are kept on all companies paying the sewage surcharge. Several funds are maintained to account for operating expenditures, sewerage surcharges, and construction projects.

Sewerage Service Charge

Activities of the Sewerage Service Charge Section were directed to the task of converting from the old rate of $0.06 per 100 cu. ft. to the new rate of $0.08. New accounts were processed; further investigations were made on industrial accounts necessitated by changes in water usage or

processes; and the effect of sewer extensions and new construction was studied.

All political subdivisions of the metropolitan service area were now incorporated with the City of Cincinnati for the treatment of sewage and industrial wastes. Of the total water accounts in the Metropolitan Sewage Disposal Area, 92 per cent are subject to sewerage service charges.

Industrial Wastes

In January 1953 an ordinance was enacted establishing standards for the discharge of sewage or industrial wastes to the sewer system or natural drainage in the metropolitan area. A surcharge was also formulated for industrial wastes.

Prior to the enactment of this ordinance considerable work was done in obtaining information from the local industries on their wastes. Information was obtained from questionnaires and investigations. Over 1,900 companies were contacted; 294 were subject to the surcharge.

The laboratory at the Little Miami sewage works was activated in May to analyze the industrial wastes samples collected by the field crews. More than 12,000 flow readings and samples were obtained.

Planning and Design

The year marked the culmination of planning activities entailing new construction in the Little Miami area. Construction was completed on the treatment works and the major interceptors.

The Mill Creek area received concentrated attention both on planning and design. Contracts were awarded for clearing the treatment plant site and construction of several major interceptors.

Little Miami Sewage Works

The first raw sewage was pumped into the works on October 5, 1953. Prior to the time of actual operation extensive preparation was completed. This consisted of:

1. Recruitment of operating personnel followed by comprehensive instruction.
2. Preparation of a 16-page dedication booklet.
3. Preparation of a 130-page sewage plant operation manual.
4. Stocking of tools, spare parts, and auxiliary machinery.
5. Preparation of a visible file system for personnel, equipment, budget, and preventive maintenance.
6. Emergency flood protection and evacuation.
7. Placing the laboratory in operation.
8. Observation and inspection of construction progress.

Treatment plant activities in October were concerned chiefly with testing and placing the plant equipment in operation. Extreme dry weather produced a minimum flow resulting in some difficulty with the separation of organics from the grit. Comminutors, chemical feeders, flocculation-settling tanks and digesters were checked.

Only one-half of the plant capacity was utilized. Digesters were heated to 85° F. and solids decomposition was

TABLE I.—Operating Data for the Little Miami Sewage Works, Cincinnati, Ohio, for December, 1953

Item	Average
Flow (m.g.d.)	10.24
Screenings, wet (cu. ft./m.g.)	1.04
Total solids, raw (p.p.m.)	1,049
Suspended solids:	
Raw (p.p.m.)	321
Effluent (p.p.m.)	103
Removed (%)	65.6
B.O.D., 5-day:	
Raw (p.p.m.)	187
Effluent (p.p.m.)	107
Removed (%)	42.8
Gas production (cu. ft./day)	41,700
Digester loading (lb. dry sol./cu. ft.)	1.59
Dry solids, raw sludge (%)	10.3
Vol. solids, raw sludge (%)	66.8

well established within 30 days. However, at pH 5.5 very little methane was produced and the gas had not been utilized by the end of the year.

Public Relations

An "open door" policy was adopted by the Sewage Disposal Section after the enactment of the industrial wastes ordinance. Industry was invited to meet with the section staff and many problems were amiably settled in round-table discussions. This policy did much to improve public relations.

Civic, business and professional groups were addressed in an effort to promote a better understanding of the sewage disposal program.

Operating data for 1953 are presented in Table I.

OHIO SEWAGE PLANT COSTS ANALYZED *

By F. H. Waring

Chief Engineer, Ohio Department of Health

The average family in Ohio buys its share of a sewage treatment plant for less money than it pays for the family washing machine.

This is shown in a survey of construction costs of sewage treatment plants in 29 cities and 19 villages. The cost study was made by the Division of Sanitary Engineering, Ohio Department of Health.

One small city of slightly more than 12,000 population is building a new sewage treatment plant at a cost of $18 per capita. The plant is designed with extra capacity to take care of growth in population. Cost per capita based on the "design population" or actual capacity of the plant is only $11.

This city admittedly had a number of special factors in its favor. It is located on a large stream so that only primary sewage treatment is necessary to provide adequate protection against pollution. Furthermore the new plant is being built on the same site as an older plant, which offers some economies.

But admitting that this is an unusual case, the average cost of primary treatment plants in 12 cities is still low. The average is $38 per capita on the basis of present population of the 12 cities. And on the basis of design population or actual capacity of the 12 treatment plants, the average cost is $26 per capita.

Costs are higher, of course, where complete treatment is necessary; and per capita costs are generally higher in villages than in cities.

The average cost per capita for plants providing secondary or complete sewage treatment in 17 cities was revealed as $57 on the basis of present population and $36 on the basis of design population.

An analysis of costs of primary treatment plants in six villages showed a per capita cost average of $53 on the basis of present population and $29 on the basis of treatment plant capacity.

A similar study of the costs to 13 villages for complete treatment plants showed an average per capita cost of $77 on the basis of present population and $53 on the basis of the design capacity of the treatment plants.

* Condensed from *Clean Waters for Ohio*, 3, 3 (1955).

It is important to consider design capacity of treatment plants as well as actual population of municipalities in evaluating costs. It is customary for all communities to build sewage plants with sufficient capacity to allow for expected growth. Communities which are growing rapidly, however, must build plants with greater margin than others; while the per capita costs in such towns will appear unusually high on the basis of current population, the rapid growth of population will soon make use of the extra capacity of the plants—and at the same time help to share the costs at a lower per capita figure.

In some towns, extra capacity in sewage treatment plants is provided to take care of industrial wastes. These wastes usually are calculated on a basis of population equivalent.

It is necessary to analyze costs in individual towns for complete understanding of each case. The averages presented in the study of costs reported here should not be considered as representative of what fair costs should be, although they can be used as a general guide.

Numerous other factors cause variations in costs for different towns. Unusual foundations, rock excavation, and high ground-water conditions are examples. Also, in some instances higher first costs may be justified by lower operating costs.

Attempting to limit the variable factors as much as possible in this study of costs, only the costs of sewage treatment plants alone were used —leaving out entirely any reference to sewers, pumping stations and other appurtenances of a sewerage system.

Of the 49 municipalities included in the survey, three completed treatment plants in 1949, three in 1951, five in 1952, eleven in 1953, eight in 1954, eleven have plants under construction now, and seven have not started construction but have recently completed final plans and estimates of costs.

In all cases the costs have been adjusted to 1954 construction costs as based on an index used by engineers in this field.

Costs are calculated in all cases on a per capita basis as related to: (a) actual population in the 1950 census, and (b) design population of the plants.

In addition to the average costs in each category, the tables also offer the median or mean cost in the town which fell into the middle of each group. Maximum and minimum costs also are shown.

Because of the adjustment in costs to the 1954 index, tabulations of the individual towns have little meaning. Therefore only the maximum, minimum, mean, and average figures are included.

Among the villages are included six with population of less than 1,000. The largest population group involved in the study was that section of Cincinnati served by the new Little Miami sewage treatment plant. This plant serves a population of 113,000. Cincinnati is now building a second plant and is completing plans for two more. But only the one plant and population served by it is included in this analysis of costs.

With these explanations, here are the cost tables as developed:

Cities—Complete Treatment

(Pop. 5,153 to 116,912; median 8,905)

	Per Capita Costs 1950 Census	Design Population
Total—17 cities		
Average	$ 57	$ 36
Maximum	87	50
Mean	55	33
Minimum	38	26

Cities—Primary Treatment

(Pop. 6,329 to 113,000; median 21,324)

	Per Capita Costs 1950 Census	Design Population
Total—12 cities		
Average	$ 38	$ 26
Maximum	57	48
Mean	37	22
Minimum	18	11

Villages—Complete Treatment

(Pop. 696 to 4,112; median 2,149)

	Per Capita Costs 1950 Census	Design Population
Total—13 villages		
Average	$ 77	$ 53
Maximum	122	88
Mean	78	47
Minimum	47	33

Villages—Primary Treatment

(Pop. 700 to 4,514; median 2,101)

	Per Capita Costs 1950 Census	Design Population
Total—6 villages		
Average	$ 53	$ 29
Maximum	120	39
Mean	52	26
Minimum	24	22

SLUDGE CONCENTRATION IN LAGOONS

The successful lagooning of sewage and sludge stimulated considerable interest at the Boise, Idaho, sewage treatment plant. Although the Boise plant does not have any problems in handling raw sewage, there have been some problems in handling surplus digested sludge. A trial arrangement was proposed for lagooning the digested sludge.

Lagooning digested sludge is not a new undertaking either at this plant. However, the purpose of this lagoon was a little different. The removal of excess water from the sludge and the resulting sludge concentration were the principle considerations. Accordingly, an existing lagoon was divided crosswise into three sections. The division walls were constructed of earth with two gravel filled portions in each wall. These gravel spots were lower than the adjoining earth wall and acted as spillways as well as filters.

As the first section of the lagoon filled separation of the solids and water occurred. The solids built up near the influent end of the lagoon and a fairly clear effluent filtered through to the second section. Settling in this section, together with the filtering action through the gravel wall sections, provided additional clarification of the water. Considerable clear water was collected in the third section.

This separated water is an excellent liquid fertilizer and was pumped to the plant lawns, resulting in a thick green carpet of fast-growing grass.

TROUBLE CHART FOR CENTRIFUGAL PUMPS *

CHECK CHART FOR CENTRIFUGAL PUMP TROUBLES

TEN SYMPTOMS	POSSIBLE CAUSE OF TROUBLE (Each number is defined in the table below)
Pump does not deliver water:	1– 2– 3– 4– 6–11–14–16–17–22–23
Insufficient capacity delivered:	2– 3– 4– 5– 6– 7– 8– 9–10–11–14–17–20–22 23–29–30–31
Insufficient pressure developed:	5–14–16–17–20–22–29–30–31
Pump loses prime after starting:	2– 3– 5– 6– 7– 8–11–12–13
Pump requires excessive power:	15–16–17–18–19–20–23–24–26–27–29–33–34–37
Stuffing box leaks excessively:	13–24–26–32–33–34–35–36–38–39–40
Packing has short life:	12–13–24–26–28–32–33–34–35–36–37–38–39–40
Pump vibrates or is noisy:	2– 3– 4– 9–10–11–21–23–24–25–26–27–28 30–35–36–41–42–43–44–45–46–47
Bearings have short life:	24–26–27–28–35–36–41–42–43–44–45–46–47
Pump overheats and seizes:	1– 4–21–22–24–27–28–35–36–41

FORTY-SEVEN POSSIBLE CAUSES OF TROUBLE

Suction Troubles

1. Pump not primed
2. Pump or suction pipe not completely filled with liquid
3. Suction lift too high
4. Insufficient margin between suction pressure and vapor pressure
5. Excessive amount of air or gas in liquid
6. Air pocket in suction line
7. Air leaks into suction line
8. Air leaks into pump through stuffing boxes
9. Foot valve too small
10. Foot valve partially clogged
11. Inlet of suction pipe insufficiently submerged
12. Water-seal pipe plugged
13. Seal cage improperly located in stuffing box, preventing sealing fluid entering space to form the seal

System Troubles

14. Speed too low
15. Speed too high
16. Wrong direction of rotation
17. Total head of system higher than design head of pump
18. Total head of system lower than pump design head
19. Specific gravity of liquid different from design
20. Viscosity of liquid differs from that for which designed
21. Operation at very low capacity
22. Parallel operation of pumps unsuitable for such operation

Mechanical Troubles

23. Foreign matter in impeller
24. Misalignment
25. Foundations not rigid
26. Shaft bent
27. Rotating part rubbing on stationary part
28. Bearings worn
29. Wearing rings worn
30. Impeller damaged
31. Casing gasket defective permitting internal leakage
32. Shaft or shaft sleeves worn or scored at the packing
33. Packing improperly installed
34. Incorrect type of packing for operating conditions
35. Shaft running off center because of worn bearings or misalignment
36. Rotor out of balance resulting in vibration
37. Gland too tight resulting in no flow of liquid to lubricate packing
38. Failure to provide cooling liquid to water-cooled stuffing boxes
39. Excessive clearance at bottom of stuffing box between shaft and casing, causing packing to be forced into pump interior
40. Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve
41. Excessive thrust caused by a mechanical failure inside the pump or by the failure of the hydraulic balancing device, if any
42. Excessive grease or oil in antifriction-bearing housing or lack of cooling, causing excessive bearing temperature
43. Lack of lubrication
44. Improper installation of antifriction bearings (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.)
45. Dirt getting into bearings
46. Rusting of bearings due to water getting into housing
47. Excessive cooling of water-cooled bearing resulting in condensation in the bearing housing of moisture from the atmosphere

Centrifugal pump troubles, although they vary with the service and equipment, can generally be grouped into suction troubles, system troubles or mechanical troubles. The chart for checking these troubles will facilitate pump repair, and provide a handy tool in operator training programs. However, it must be remembered that proper maintenance does not start with repairs or replacement of worn parts, but right at the time of pump selection and installation.

* Reprinted from the Winter issue, *Power and Fluids*, courtesy Worthington Corp., Harrison, N. J.

TIPS AND QUIPS

Oxidation Ponds and Lagoons

After reading about the use of sewage oxidation ponds and lagoons for disposal of sewage in the arid regions of the West, it is interesting to note some other uses for this old but versatile means of sewage treatment.

At Oceanside, Calif., the experimental oxidation pond receives raw sewage at peak flows and recirculated pond effluent. Two objectives are involved: (a) To store excess raw sewage during high flows, and (b) to recirculate pond effluent through the plant to cut down on odors. There is a good growth of algae and reports indicate as much as 33 p.p.m. of oxygen at mid-day.

An activated sludge sewage treatment plant near Clearwater, Fla., utilizes a small lagoon for effluent polishing. The chlorinated effluent is discharged to this lagoon, where luxuriantly growing water hyacinths apparently act as mechanical and biological strainers, to produce an effluent of sparkling quality.

Sensitive Sniffer

An experimental gas-leak detector is under development with a sensitivity to hydrogen, bottled fuel gas, alcohol vapor, natural gas and other flammable gases. It will spot a leak as slow as 1 cu. in. an hour. In the way it is used, the new detector is similar to the previously developed electronic "sniffer." In addition, it is extremely sensitive to halogen gases (chlorine).

Look out leak!

More Slag Used

According to a mineral industry survey by the U. S. Bureau of Mines, the use of slag as a trickling filter medium in sewage treatment plants has nearly doubled. In 1952 slag tonnage amounted to 48,168 tons and in 1953 it increased to 89,679 tons valued at $142,308. This is an indirect indication of the number and type of new sewage treatment plants providing secondary treatment.

Remote Sampling

Sampling highly radioactive process streams is one problem that continually troubles scientists and engineers in the atomic energy field. Laboratory analysis is often necessary because of the number and complexity of constituents in the waste stream.

To accomplish this more conveniently and with less possibility of radiological hazards, a remote sampler has been developed by one of the nation's leading atomic-energy developers. A sample is removed from the waste by an air jet that raises the portion to a sample cup. By means of a remote pipetter, a measured quantity is removed and placed in a dilution flask. The solution remaining in the sample cup is recirculated to the waste stream.

Industrial Water Use

Water intake during 1953 by manufacturing establishments using 20 m.g. or more amounted to 11,400,000 m.g. according to the latest (1953) Annual Survey of Manufacturers results released by the Bureau of the Census, Department of Commerce.

Over 2,000,000 m.g. was brackish (salt), and about 3 per cent of the water is recirculated. Approximately 20 per cent of the total fresh-water intake was obtained from public supplies; the balance came from company operated supplies (67 per cent surface water and 13 per cent ground water).

Per employee water use varied from 24 m.g. per year for blast furnaces to 30,000 gal. per year for the aircraft industries.

The Spoonula

A new all-purpose lab implement designed as a stainless-steel spoon at one end and a keen-edged spatula at the other (Figure 1) has been introduced by Fisher Scientific, 717 Forbes St., Pittsburgh, Pa.

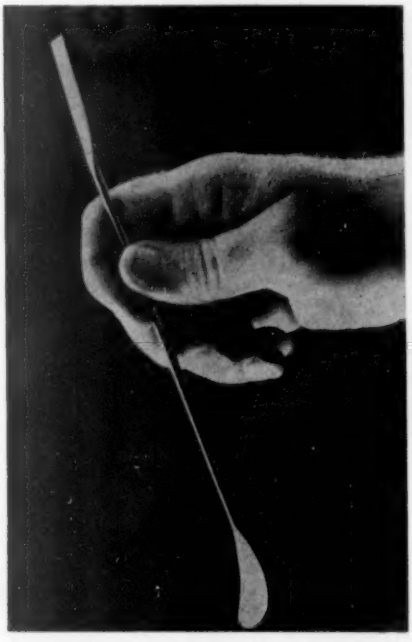


FIGURE 1.—Spoonula, combination spoon and spatula.

Heretofore it has been just about impossible to get powder or crystals out of the bottom of the reagent bottle with a spatula without spilling some. Now the reagent can be spooned out with the scoop-end, and with the flat spatula-end the sample can be delivered to the balance pan, grain by grain. The 9-in. long corrosion-resistant stainless-steel spoonula can be used for breaking up caked samples.

Incidentally, it's also fine for cheese spreads and other delicacies.

Engine Wear Meter

Lubricating oil viscosity is indicative of the effectiveness of the engine lubricant. Fuel dilution, cooling system leakage, dirty filters, and wrong grade make-up oil contribute to engine wear by changing the viscosity of the oil.

A viscosity meter that responds only to viscosity changes caused by a change in oil composition has been introduced by the Gerin Corp., Avon, N. J. Unaffected by temperature changes, the meter is reported to be accurate within 1 per cent. It is designed as a sturdy vibration-proof unit, that operates on the principle of comparing the viscosity of the new oil held in the meter with that of the circulating oil from the lubricating system.

King-Size Pipe

Eliminate a sewer pipe joint and you eliminate a problem, both today and tomorrow.

In response to the growing demand for longer pipe and fewer sewer joints, the Logan Clay Products Co., Logan, Ohio, has announced the production of vitrified clay pipe in 5-ft. lengths. This longer pipe is available in diameters of 18-, 21-, and 24-in. diameters, standard or extra strength, with Slip-Joint or regular bell and spigot types.

In addition to "king-size," 4-ft. lengths are available in 8-through 30-in. diameters.

Operator Wanted

The city of Waco, Texas, has need of an operator for its new trickling filter sewage treatment plant.

Qualified operators are invited to submit experience resume and salary requirements to: Mr. T. F. Collins, Assistant City Engineer, City Hall, Waco, Texas.

Book Reviews

Manual for Sewage Plant Operators. Second Edition. Texas Water and Sewage Works Assn., 2202 Indian Trail, Austin, Tex. 511 pp. Price, $6.50 (1955).

The second edition of this well-known and widely distributed operation manual represents an effort to keep the subject matter abreast of progress in the field. New concepts have necessitated complete rewriting or major revisions of 10 of the 27 chapters. A new chapter on oxidation ponds has been added because these units are coming more and more to the fore as a method of sewage treatment. Because of the small present use of sand filtration in Texas, the chapter on this treatment method has been deleted.

Chapter headings of the new edition are as follows:

1. Sewage Composition, Chemistry, and Biology
2. Sewerage and Its Relation to Public Health
3. Sewer Design
4. Lift Stations and Sewage Pumps
5. Maintenance of Sanitary Sewers
6. Organizing and Financing a New Sewerage System
7. Sewage Irrigation
8. Screens, Grit Chambers, Detritors, Grinders, and Grease Traps
9. Sewage Disposal for Residences and Institutions
10. Imhoff Tanks, Design, and Operation
11. Primary Sedimentation Tanks, Purpose, Design, and Operation
12. Chemical Precipitation of Sewage
13. Oxidation Ponds
14. Design and Operation of Trickling Filters
15. Operation of Activated Sludge Plants
16. Separate Sludge Digestion
17. Maintenance and Operation of Sludge Drying Beds
18. Mechanical Sludge Filters and Dryers
19. Chlorination of Sewage
20. Other Treatment Methods and Disposal of Sewage
21. Sewage Treatment Plant Maintenance
22. Industrial Waste Problems
23. Commercial Utilization of Sewage Treatment Products
24. Stream Pollution and Its Control
25. Laboratory Control Tests
26. Mathematical Problems Connected with Sewage Treatment and Disposal
27. Texas State Standards for Design, Operation, and Reporting

Appendices outline the Texas operator certification plan; give a condensed glossary of sewage engineering terms; summarize occupational hazards and safety practices; tabulate useful information, formulas, and conversion factors; and list publications of most use to operators and plant administrative personnel. An excellent 15-page index makes the volume of maximum possible benefit to the user.

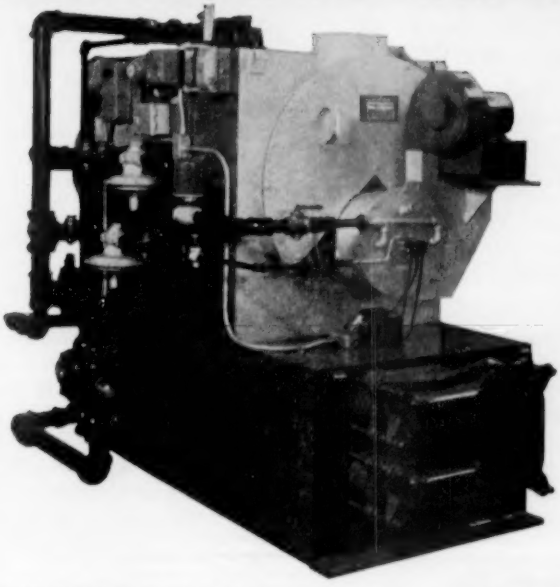
H. P. O.

Handbook of Drainage and Construction Products. Armco Drainage & Metals Products, Inc., Middletown, Ohio. 579 pp. Price, $5.00 (1955).

This latest edition of a well-known drainage handbook brings up-to-date the information, data, and field observations on materials, products and methods used in culvert, drainage, and sewer construction. Although naturally concerned with the products of one company, the basic knowledge accumulated in this unique book certainly makes it a must item in the library of every engineer and designer. H. P. O.

WALKER PROCESS

HEATX UNIT
Digester Heat Exchanger



370,000 BTU/hr. HEATX for installation at Villa Park, Illinois. Burner automatically utilizes sewage gas or natural gas separately or in combination. A pre-ignition purge cycle clears the combustion chamber of any fuel accumulation before starting or between fuel switch-over.

FORCED TURBULENT CIRCULATION
HIGH RATE OF HEAT TRANSFER
NO SLUDGE ADHESION

The HEATX is designed to allow absolute and independent control over each function of sludge heating; namely, heating of jacket water, control of temperature and flow of jacket water and control of digester temperature and rate of turnover.

The HEATX is offered as either a separate exchanger, for use with existing standard boilers or as a package unit complete with a Walker Process boiler and burner. Boilers are designed to burn sewage gas, sewage gas and oil or sewage gas and natural gas.

The concentric tube type exchanger is equipped with special removable end castings arranged to prevent contamination of the heating water by material circulated through the sludge tubes.

Write for Bulletin 24S82.

Engineering and manufacturing a complete line of water, waste and sewage treatment equipment.

WALKER PROCESS

WALKER PROCESS EQUIPMENT INC.
Factory — Engineering Offices — Laboratories
Aurora, Illinois

Proceedings of Member Associations

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 27th Annual Meeting of the New York Sewage and Industrial Wastes Association was held at the Belmont-Plaza Hotel, New York, N. Y., January 20–21, 1955. A record high of 294 persons registered for the meeting.

Papers presented at the technical sessions included:

"Treatment of Sanitary Sewage and Industrial Wastes in the Pearl River Plant," by D. M. Ditmars, Clinton L. Bogert Associates, and J. R. Scovill, Superintendent, Pearl River Sewer District.

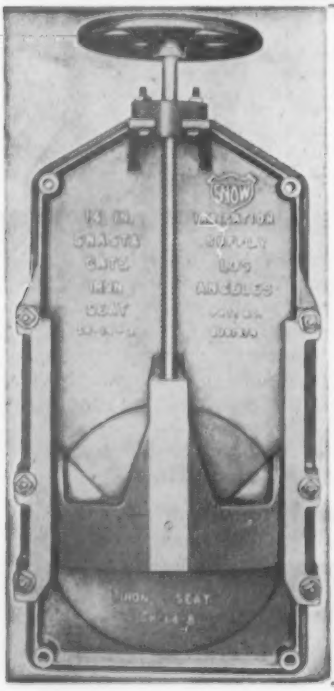
"Sampling of Industrial Wastes," by W. M. Steinfeldt, Waste Engineer, Eastman Kodak Co., Rochester.

"Treatment of Ceramic Wastes at the Locke Plant, Baltimore, Md.," by G. M. Boyd, Supervisor of Inspection and Quality Control, Locke Dept., Baltimore, Md., and K. S. Watson, Consultant, Water Management and Waste Control, General Electric Co., Schenectady, N. Y.

"Ground Water Pollution from Industrial Wastes in Nassau County, N. Y.," by W. F. Welsch, Nassau County Dept. of Public Works, Mineola.

"Treatment of Wastes Containing Hexavalent Chromium and Organic Matter," by John J. Baffa, Consulting Engineer, New York City, and Harold E. Orford, Chairman, Dept. of Sanitation, N. J. Agricultural Experiment Station, New Brunswick, N. J.

(*Continued on page 296a*)



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SEWAGE TREATMENT PLANTS

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Over 40 years continuous service to the industry.

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2437 East 24th Street Los Angeles 54, Calif.

THE SUN'S HEAT AND GIANT REFLECTORS may convert cosmic energy into power that will propel space ships to distant planets.

100 years from now...

WE MAY "SIGHT SEE" ON MARS

A century from now, when undreamed-of marvels transform our way of life, civilization will still rely on one familiar public servant: the cast iron pipe laid today will continue to carry water and gas to the homes of the future.

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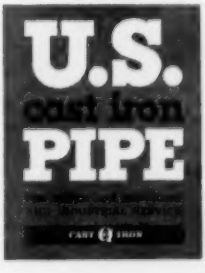

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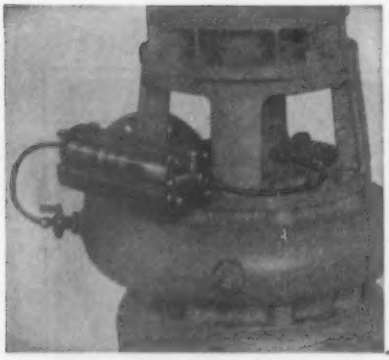

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(*Continued on page 298a*)

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Of interest to sewage and industrial waste treatment personnel were technical papers on suspended solids reactor use, waste disposal at Air Force Stations, and aspects of water sanitation relating to fresh and saline waters.

A considerable portion of the program was devoted to air pollution and related problems, with several excellent papers.

Officers elected to serve the Sewage and Industrial Wastes Section for 1955–6 were as follows:

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2nd Vice-Chairman: G. A. Doty, Breckenridge.
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Asst. Secretary-Treasurer: Mrs. E. H. Goodwin, Austin.

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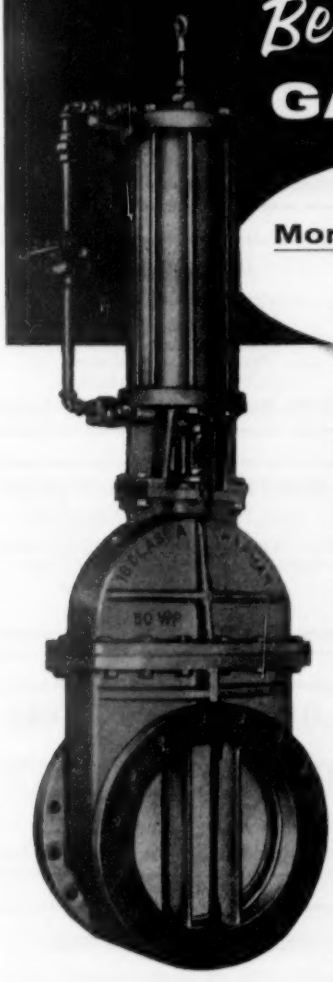

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